CRANFIELD UNIVERSITY

WEI-CHUNG LIU

Development of a Strategically Driven Production Facilities Management (PFM) Framework

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

PhD THESIS

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Academic Year 1999-2000

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June 2000

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

ABSTRACT

This thesis presents the results of a programme of research into the development and evaluation of a strategically driven Production Facilities Management (PFM) framework. PFM is the activity of managing production facilities to fully realise the corporate strategic objectives of a manufacturing organisation.

Companies with strategies tend to be more successful than companies without them. The concept of manufacturing strategy is an approach to enhance the consistency between the manufacturing function and the direction of the organisation. Consequentially, PFM is the means to ensure these strategic requirements can be fully realised from the facilities management viewpoint. Through the literature review, it was seen that there is a lack of a link between manufacturing strategy and the management of production facilities. From questionnaire surveys and interviews at companies in the manufacturing sector, it was found that the issue of linking facilities management with corporate strategy has been ignored. Therefore, this programme of research not only investigates the context and contents in formulating an appropriate manufacturing strategy in a manufacturing environment but also reviews the most popular methods in relation to maintenance management and performance assessment of the facilities.

This programme describes the development of a strategically driven, step-by-step approach that helps a company to capture the strategic requirements of the manufacturing function, measure the performance of existing production facilities and supports the decision-making analysis tasks. The primary contribution of the work presented in this thesis was the development of an implementation framework and an associated implementation workbook which comprise a set of stages and implementation sections that a user can use to carry out the process of capturing the strategic requirements and realise them with support from an appropriate PFM framework and a systematic, step-by-step implementation process.

ACKNOWLEDGEMENTS

I would like to thank a number of people that have contributed to this research programme. There are too many to mention them all by name. However, I would like to mention a few specially.

My sincere thanks are offered to my supervisors Professor John M. Kay and Mrs Gwyn Groves who have been my academic guides during this research programme. I would like to thank them for their continued help, support, encouragement and commitment to my studies.

I would like to thank all of the academic staff, Dr. Bin Wu, and Dr. Richard Greenough, and the friends that I had while I have been at Cranfield, Dr. Michael Ince, Mr. Kuang-Chung Huang, Yun-Lung Chang, and Chia-Ping Huang, for their friendship and their encouragement.

Finally, my special thanks are offered to my dear wife Mrs Hui-Ying Yang and my daughter Miss Ming-Chun Liu for their constant support in getting me where I am today and where I will go in the future.

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NOTATION AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
AMT	Advanced Manufacturing Technology
BCM	Business Centred Maintenance
BPR	Business Process Reengineering
CALS	Computer Aided Logistics Support (Continuous Acquisition and Life-cycle Support; Commerce At Light Speed)
CE	Concurrent Engineering
CIM	Computer Integrated Manufacturing
CBM	Condition Based Maintenance
CLM	Council of Logistics Management
CMMS	Computerised Maintenance Management System
DTI	Department of Trade and Industry
EDI	Electronic Data Interchange
EQA	European Quality Award
ERP	Enterprise Resource Planning
FMEA	Failure Mode and Effectiveness Analysis
FMS	Flexible Manufacturing System
GT	Group Technology
ILS	Integrated Logistics Support
IS	Information System
IT	Information Technology
JIT	Just In Time
LCC	Life Cycle Cost
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
MCDM	Multiple Criteria Decision Making
MRP	Material Requirement Planning
MRPII	Manufacturing Resources Planning
MIS	Management Information System
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement
MTTR	Mean Time To Repair
OEE	Overall Equipment Effectiveness
OPT	Optimised Production Technology
PdM	Predictive Maintenance
PFM	Production Facilities Management
P.I.	Performance Indicators
PLC	Product Life Cycle
PM	Preventative Maintenance
P.M.	Performance Measures
PMS	Performance Measurement System
QFD	Quality Function Deployment
RCM	Reliability Centred Maintenance

SOLE	Society of Logistics Engineering
SPC	Statistic Process Control
SWOT	Strengths, Weaknesses, Opportunities and Threats
TPM	Total Productive Maintenance
TQM	Total Quality Management
UV	Utility Value
WCM	World Class Manufacturing

CHAPTER 1
INTRODUCTION

1.1 Introduction

Today's highly competitive manufacturing environments encourage companies to work smart, rather than work hard (Gundogan, 1995). This applies to every kind of manufacturing industry. The emphasis on quality, customer satisfaction, flexibility, just-in-time manufacturing, and changing management styles represents a quiet revolution being acted out in thousands of companies and production plants throughout the whole world (Maskell, 1991). But for many companies it has been, and continues to be, a struggle and some have not survived. One of these issues may come from a weak Production Facilities Management (PFM). For example, maintenance is one of the key elements of PFM, but there is strong divergence as to whether maintenance practice is an engineering or management discipline (Edwards, *et al*, 1998). PFM will become more and more complicated due to the fast growth of advanced technology with the characteristics of equipment changing as well. The requirements of equipment characteristics to be modular, robust, and flexible means that module changes, continuous returns, and no failures become the basics of survival in the 2000s (Campbell, 1995). Inherently, the PFM framework can involve both disciplines which means it will require the background to engineering practice and an insight into management practice. This research is intended to implement a profound research in "How to make a successful PFM to survive in the integrated manufacturing environment."

1.2 Background of the Research

The Nature of Manufacturing – Competition for Survival

Manufacturing is an organised activity devoted to the transformation of raw materials into profitable goods in the market. The key elements for the core conversion activities are facilities or hardware, procedures or software, and people or humanware (Basu, 1997). In commerce, the primary and basic objective is to survive, or at least to balance production and consumption. To survive, one must compete and competition is the process by which the market seeks to solve the basic economic problem of maximising satisfaction from the consumption of scarce resources (Baker & Hart, 1999). The market of today demands high variety, small batch volume products of high quality (Wu, 1994). However, "*The manufacturing field presently is undergoing changes that would have been quite difficult to predict a decade ago*" (Bedworth and Baily, 1987). To face the new challenges Baker (1999) and Doyle (1995) pointed out *that "The fortunes of the company are not only tied to its products but also to five other primary forces which determine its ability to maintain a competitive advantage.*" These five forces are:

- The changing requirements of customers.
- The objectives and strategies of competitors.
- The attractiveness of the market to new competitors.
- The emergence of new technologies which can replace existing solutions.
- The performance and power of those companies supplying resources, raw materials and components to the business.

After an extensive review of research in production / operations management, Voss (1992) concluded *that "If U.K. manufacturing companies are to regain competitiveness, better management of production operations is required. The academic community has a strong part to play in this in identifying, developing, and transforming good management practice.*" Wu (1994) argues *that "even though academics and practitioners involved in manufacturing have been trying hard to find ways to maintain and increase manufacturing competitiveness, there are still many obstacles in achieving and maintaining a high competitiveness.*" According to the observations of Voss (1992) and Wu (1994), the main issues that prohibit the competitiveness of the manufacturing business are typically:

- Failure to invest in new plant and equipment;
- Insufficient management practices;

- Lack of coherent manufacturing strategy;
- Inadequate educational and professional training system;
- Lack of awareness of the importance of manufacturing;
- High cost of materials and labour;
- Unfair overseas competition; and
- Cultural background and social attitudes.

All of these aforementioned items can be divided into hardware and software issues. The hardware issue is concerned with the actual handling and processing of materials on the shop floor which very much depends on Production Facilities Management (PFM). The software issue is linked to the handling and processing of manufacturing and management information, and thus planning and control of the manufacturing resources effectively and efficiently. The software issue is often discussed from the strategic viewpoint.

The nature of the manufacturing strategy formulation process can be summarised as a method to help a company analyse its products, market and operations so as to identify areas of concern, and set objectives for the improvement of these areas. Increase capacity, enhance product quality and service and improve labour productivity; these demands are familiar to the manufacturing industry. Although it has been suggested that manufacturing industries can become more productive by employing new and more sophisticated equipment and techniques, surveys (Miller *et al*, 1981; and Wu, 1994) have shown that the most significant factor is still the effectiveness of the administrative system. These arguments highlight the importance of appropriate strategic concerns and decisions which will lead to the success of the business in the end.

In reality, the efficient and reliable operation of the facility is one of the key factors in running a business for any manufacturer. Gotoh (1991) stated "*True competitiveness comes from the synergetic combination of product development capability and rigorous development of equipment and related fabrication methods to produce high quality products at low cost.*" The production facilities provide the essential resources to accomplish all of the product demands on one side, whilst the shutdowns and uncontrolled maintenance costs of them are the enemies of manufacturers on the other. The effective capacity of any enterprise is maximised by managing disciplined processes across the production line and by tracking the performance, maintenance and the history of the physical facilities.

Capacity and efficiency are optimised by integrating all plant processes, eliminating the need to discretely manage for labour, material, tools, and equipment. Facilities definition, establishment of Preventive Maintenance (PM) and Predictive Maintenance (PdM) programmes, planning and scheduling the maintenance activity, and analysis of maintenance and control programme effectiveness, decision-making of maintenance, enhancing or replacing existing facilities all contribute to the complete management of the facilities throughout their life cycles.

This research is concerned with the development of a generic management framework of effective Production Facilities Management (PFM) for the manufacturing industry. The aim is to help companies achieve competitiveness, specifically structured to help manufacturing companies in formulating a decision-making procedure, the proper policy of maintaining existing facilities and developing a Performance Measurement System (PMS) in an integrated manufacturing environment.

1.3 Contemporary Requirements of Manufacturing Business

How can companies be successful? The answer is the basic Darwinian theory "*Evolution of the species, only the fittest survive.*" The new species displace the old species because they are better adapted to the prevailing environmental conditions. Tompkins (1996) observed the social environment for manufacturing business towards the 21st century and summarised the stages of progression from traditional manufacturing to contemporary manufacturing, as shown in Figure 1.1.

Past ——→ Present ——→ Future

Traditional Manufacturing	Uncoordinated Incremental Improvements	Focused and Co-ordinated Product and process Improvement	Contemporary Manufacturing
•Hierarchical Management •Functional focus •Impersonal management •Minimum training •Mass production, inflexible process •Long production runs •Long lead times •Adversarial relationships with suppliers, customers, and employees •Focus on full machine and labour utilisation	•Waste elimination focus •Participation management •Management committed to the quality improvement process •Extensive education and training begins •Fewer management layers •Awareness of total cost of quality •"Pilot" projects •Developing supplier relationship •More open communication	•Minimum management layers •Flexible manufacturing •Smaller lots •Quicker response to customer •Detailed process studies •Just-In-Time purchasing and manufacturing •Focused plant layouts •Work cells •Statistical control •Reserve capacity •Preventative maintenance •Employee involvement teams •Cross-trained workforce with job rotation	•Customer service excellence •Error-free work •100% on-time delivery •Paperless business •Short lead-times, quick response •Customer/supplier partnerships •Constant innovation •Produce to customer needs •Low inventories, small lots •Self-managed teams

Figure 1.1. Stages of progression from traditional manufacturing to contemporary manufacturing (Source: Tompkins, 1996)

According to Tompkins's theory, the enemy of the evolution of manufacturing management is the tradition. Keen competition in industry and customers' never ending change requirements place manufacturers under constant pressure to become more efficient. This forces the industry to evolve towards being more flexible and productive (Wu *et al*, 1998). Coincidentally, the business of today is under enormous dynamic pressure from the customer and is forced to be financially productive. Many researchers have concluded that the manufacturers of today must adopt measures for manufacturing excellence and they also advocated that manufacturing industry should set World-Class Manufacturing (WCM) standards to help achieve these dynamic requirements (Maskell, 1991), (Stonebraker and Leong, 1994), (Kaplan, 1990), (Dixon, 1990), (Todd, 1995), (Hill, 1995), (Slack, 1998), (Wild, 1995), and (Voss, 1992).

From a strategic viewpoint, to be World Class, means a business has to achieve the best performance in its field in the world. "Best can be in terms of (Todd, 1995):

- "*Product design and performance*"

- *"Quality and reliability"*
- *"Least manufacturing cost"*
- *"The ability to introduce innovative designs more quickly than the competitors"*
- *"Shorter lead times and more reliable delivery performance"*
- *"Better customer service."*

These major requirements from customers constitute the strategic competitive criteria such as cost, quality, flexibility, delivery, customer service. From a practical operations viewpoint, the dictum is maximising output of goods and services and minimising input of resources – financial, human, and physical. The purpose of an appropriate PFM is to guarantee that all resources are capable of satisfying these strategic objectives. Consequently, PFM is required so as to make the products in the right quality, at the minimum cost, and to deliver them to the customer right on time for customer satisfaction.

A company's manufacturing function is typically either a competitive weapon or a corporate millstone. The decisions in manufacturing frequently influence and limit the corporation's strategic options, in particular the ones with capital values like, the facilities, equipment and personnel. A non-competitive policy and control will require years to turn around. The critical issue is the missing link between facilities management and implementation of manufacturing strategy.

The precision and criteria of maintenance historic data collection and analysis is the key to make an appropriate PFM work. Edwards (1998) *stated "Historical and statistical records of plant items must be maintained, but unfortunately, research has identified that this is not the case."* Historic data not only allows an assessment of a policy's success or failure, but more importantly provides a useful benchmark standard against which to judge the effectiveness and efficiency of the policy in the future. A lack of historic data will mean that reactive maintenance might happen later on. This does not commensurate with production facilities management. The choice of these criteria must be determined by commitment of the corporation. For businesses that run on large, sophisticated equipment and facilities, maintenance performance has a dramatic impact on overall capacity and cost. For businesses that run small to medium business, PFM is also important because of the more flexible and small lot size of the production it will require. Boznos (1997) reported "*Traditionally, these kind of activities were based on reactive, fire-fighting, corrective maintenance approaches, or on Planned Maintenance (PM) practices that take mainly the form of equipment overhaul or item repair, item replacement at fixed intervals.*" For a long time, the responsibility of keeping all of the production facilities available when required belonged to the maintenance department. Some of the small to medium companies do not even have a maintenance department to take care of the facilities management works.

Campbell (1995) reported that "*In most companies, business suffers because they don't pay enough attention to maintenance.*" In 1996, a downtime survey reported by Gould indicated that around one third of UK manufacturing companies were taking a 'laissez-faire' stance on downtime and not taking significant steps to address the associated problems. It also concluded that reduction of production downtime is a strategic business issue and has a major impact on the bottom line. Lack of understanding of the real cost of production downtime and failure to adequately address the problem led to poor line efficiency.

Over the past twenty years, the maintenance of existing facilities was always run by maintenance people as a whole. More and more researchers such as Moubray (1997) and Kelly (1997) reported that due to the huge increase in the number and variety of physical assets (plant, equipment, and buildings), maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. Maintenance is responding to changing expectations. These include a rapidly growing awareness that the maintenance objective should be compatible with the corporate and production objectives such as safety, product quality, plant availability, cost, etc. Kelly consequently developed his Business Centred Maintenance (BCM) strategy in 1997. Bate (1996) also pointed out that "*Effective strategies deliver plant reliability and good maintenance emphasises the need to consider plant reliability within a wider context of corporate and production objectives.*" The decision-making on maintaining, enhancing or replacing the existing facilities should be based on historic maintenance records and downtime analysis and effective PFM needs well disciplined maintenance.

Nevertheless, the issue of the in implementation of PFM has always existed because it involves much indecision due to a range of decision-makers with conflicting perceptions and requirements. From the literature surveyed, there is an apparent lack of a systematic, step-by-step approach to link the corporate strategic requirements into the production facility management activities. The PFM framework is a solution designed to fill this gap.

Production Facilities Management (PFM) is the activity of managing production facilities to fully realise the corporate strategic objectives of a manufacturing organisation. These objectives are usually best expressed as customer-oriented criteria such as delivery, quality, price and service, but may also be strategic measures such as investment, risk, flexibility, organisational learning, and financial viability. Facilities' choices must be made and trade-offs are inevitable because any system cannot be outstanding enough to meet all criteria to create a competitive advantage. The facility must be purchased, upgraded or replaced for its appropriate purpose. The PFM needs structural decisions which are internally coherent and focused on objectives that will create a competitive advantage.

In this research, there are five main elements to be discussed, they are manufacturing strategy formulation, facilities integrated logistics support, facilities maintenance management, facilities performance benchmarking and facilities life cycle assessment. The survey and development of the PFM framework is focused on all activities that are relevant to these four elements, in particular the integrated consideration and decision making of management of the production facilities from the strategic and operational viewpoint. The typical decisions to be made are maintenance, enhancement or replacement of existing equipment.

1.4 Objectives of the Research

The introduction to the thesis has shown that various technologies and techniques have been evolved to assist manufacturing to perform its function. However, there are still major problems with the possibility of achieving efficient and effective management of the facilities. The overall aim of this thesis is to review the key issues associated with the management of production facilities that relate to corporate strategy, and to produce a method of better approach to improve the performance of facility management. The method should adopt the strengths from current theories and practices from the manufacturing industry. The method should contain a series of phases and sequential steps that can be used as a tool for implementation. The method should also be flexible enough to be adapted to different situations, for example data collection and analysis.

The overall objectives of the research contained in this thesis are listed as follows:

1) Identify the gaps between theoretical approaches and pragmatic practices in relation to PFM. Discuss the strengths and weaknesses of these theories and practices.
2) Identify the requirements for a new method of strategically driven PFM framework so as to capture the strategic requirements of the business and consequentially transform them into objectives of PFM.
3) Develop a step-by-step implementation process for application in reality. The method is developed to apply the strengths of the academic approaches. Then evaluate the method and identify the results that the research indicates.

1.5 Structure of the Thesis

The structure of the thesis is listed as follows:

Chapter 1 is the introduction which identifies the research problem and states the overall objectives of the research.

Chapter 2 is the literature review which reviews the current practices relevant to PFM. The main contents in chapter 2 include:

- Main topics in the relevant area (context, framework, and themes)
- Survey of current techniques/tools/methodologies and practices in each of the main topics
- Analysis of current techniques/tools/methodologies in relation to the proposed approach (usefulness, weaknesses, gaps, missing links, etc.)
- Define the gap and new arguments.

Chapter 3 describes the research approach and methodology used to achieve the enquiry. This chapter also introduces the strategic contents discussed in this research which establishes the requirements in developing a model for the possible solution. The other main contents in chapter 3 include:

- Developing the aim of the research.
- Identifying the key issues, and the requirements for improvement.
- Data collection and analysis methodology of the research.
- Design the programme of the research.

Chapter 4 applies the strengths of the theories and methodologies to develop a conceptual PFM implementation framework and tests the conceptual model with an example test. In relation to the gap as identified in the literature survey, outline how the proposed approach aims to improve this situation. An overview of the structure of the proposed approach will be given. The main contents include:

- Conciliate the gaps between current theories and practices.
- Define the specifications of the PFM model design.
- Overview the structure of the PFM framework.
- Introduce the application of the strengths of the reviewed theories, methodologies and techniques.

Chapter 5 further develops the conceptual model into a detailed implementation process. The main contents include:

- The detailed flow chart of the developed PFM framework.
- The detailed implementation procedure which is described with a step-by-step implementation workbook.

Chapter 6 evaluates the validity of the developed PFM model. The main contents include:

- Design a test programme which includes the internal and external test.
- Given detailed example to illustrate how the proposed approach can be followed in practice.
- The design of the questionnaire and preparation for the postal survey.
- The preparation of the postal and interview survey.
- The data collection and analysis of the postal survey and interview survey.

Chapter 7 makes the conclusions and recommendations of the research. The main contents in this chapter include:

- The summary of the research aim and objectives.
- The strengths and weaknesses of the research.
- The limitation of the evaluation tests and surveys.
- The contribution of the research.
- Further research recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, several areas related to Production Facilities Management (PFM) have been reviewed. They are:

- Key issues in the changing environment of manufacturing industry
- Manufacturing strategy formulation
- Current approaches on facilities maintenance practices
- Life cycle management of facilities
- Performance measurement system development and benchmark techniques
- Decision-making support analysis techniques.

Academic methodologies and current practices are reviewed to find the gap between what is currently available to implement facilities management tasks and what may be required for further improvement of its effectiveness and efficiency. A review of the relevant papers provides a basis for the development of the structure of a framework to be suggested. The discussion addresses the strengths and weaknesses of each main area, in relation to how they can contribute to aid the establishment of a strategically driven PFM framework.

2.2 Manufacturing Business Background – The Changing Environment of Manufacturing Industry

Keen competition in industry and never ending customer change requirements place manufacturers under constant pressure to become more efficient, flexible and productive. In order to cope with the fast changing and competitive manufacturing environment, the manufacturing business becomes a broad integration of management and technology. Many management concepts and techniques have been developed and evolved.

Cheng *et al* (1998) summarised the changing manufacturing environment from the 20th century towards the 21st century as shown in Figure 2.1.

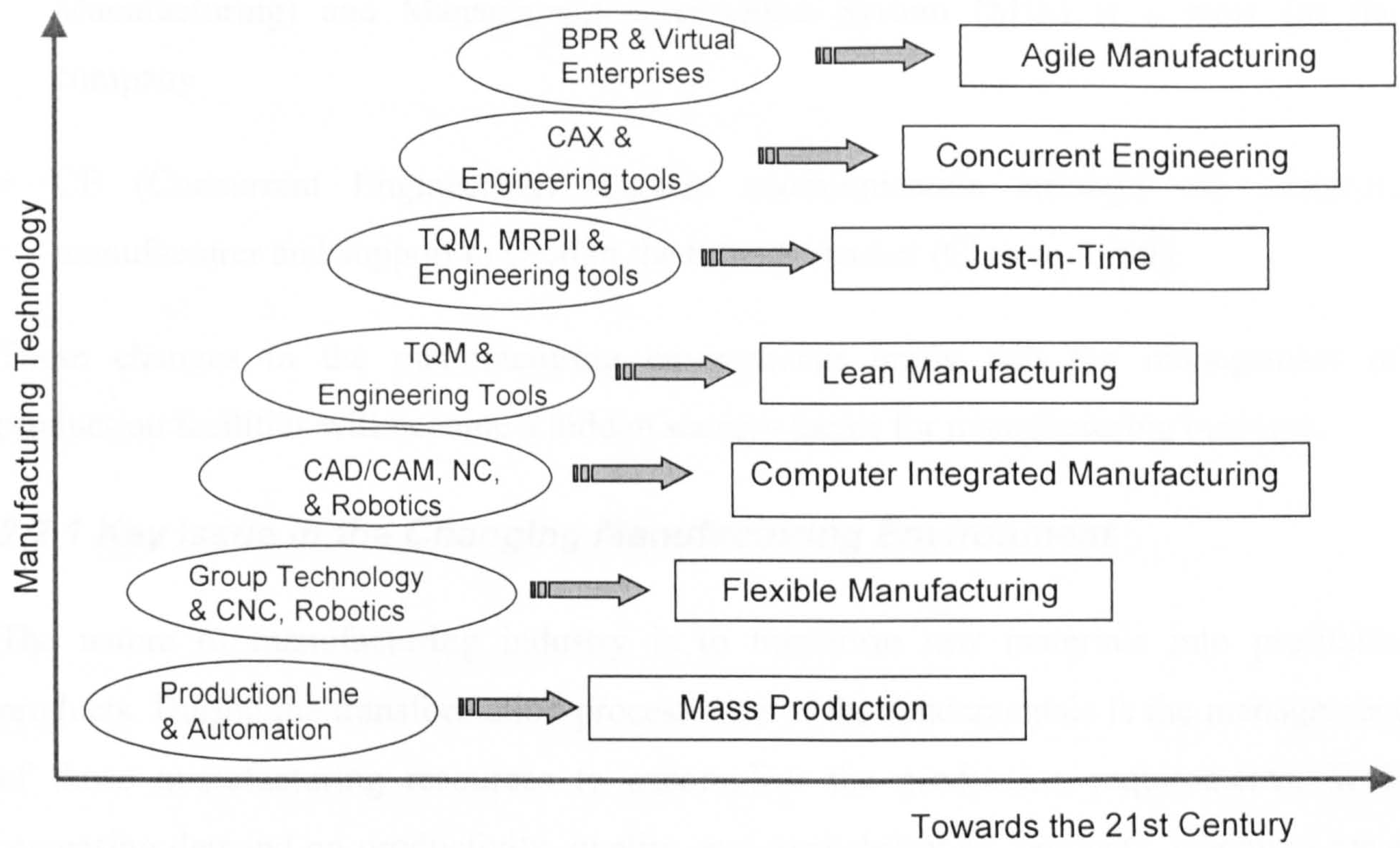


Figure 2.1 Development in Manufacturing Technology
(Source: Cheng et al 1998)

Their observation shows that the manufacturing environment has always been changing and that the manufacturing technologies were developed to cope with these changes. All of these concepts are relevant to managing manufacturing business but they are based on specialised, isolated segments and have no linkage between them. Adapted from Cheng's observation, the vital factors to be a leading manufacturer in the future are highlighted as follows:

- Enterprise integration and agile manufacturing is a vital factor for survival
- Just-In-Time and lean manufacturing requires the support of optimised production facilities planning and control

- The changing of the financially-oriented performance measures into the new kind of operation-oriented performance measurement system
- IS (Information System) /IT (Information Technology) development to assist the ability of real time data access and storage. CIM (Computer Integrated Manufacturing) and Management Information System (MIS) is a must for the company
- CE (Concurrent Engineering) requires communication amongst the designer, manufacturer and support to shorten the time-to-market (Chanan, 1994).

These changes in the manufacturing environment imply that the management of production facilities will become a hidden success factor for manufacturing business.

2.2.1 Key Issue in the Changing Manufacturing Environment

The nature of manufacturing industry is to transform raw materials into profitable products. During the transformation process, one of the fundamentals is the management of those manufacturing resources to accomplish the production requirements. With increasing demand on productivity, quality, and availability of products, machines have become more complex and capital intensive (Labib, 1998). Can technology solve all the problems of manufacturing industry? Even though investment in new equipment may have improved local effectiveness; poor planning and control, lack of understanding of the nature of the organisation, and lack of formal guidance rules to aid management decision-making, may all result in low productivity as well (Wu, 1994). This highlights the importance of linking capital investment decisions, equipment utilisation and the strategic concerns of the company. It is rare for manufacturing to be viewed from a systems perspective as an integrated combination of process, machine systems, people, organisational structures, information flows, control systems and computers, designed and operated in order properly to support a coherent strategy (Wu, 1994). To design and operate the modern manufacturing business, the managers, engineers and operators should understand the goals of the organisation, meanwhile, they must work together and possess better multidisciplinary skills.

A modern manufacturer must undertake not only the company-wide cultural change such as proper management skills, and corporate strategy, but also the operational support of production facilities. Traditionally, the majority of the management of the facilities depended on the performance of maintenance management which is treated as an action-oriented function. Maintenance people are fire-fighters who solve production problems. Their objective was to keep the process running, i.e. availability maximisation. Little time was spent on planning maintenance activities (Arts, *et al,* 1998). Most of all, the decision-making of the maintenance or replacement of production equipment was independent of the strategic requirement (Pintelon *et al,* 1992; Kelly, 1998). Today, to face global competition, small profit margins, high safety awareness and strict environmental regulations, the antiquated run-to-breakdown concept should be improved in a more active way.

2.2.2 Nature and Significance of Production Facilities Management

Facilities may be defined as follow: "*facilities are the equipment, buildings, and services that are provided for a particular activity or purpose*" (Sinclair, 1990). The PF (Production Facilities) in this PFM research means all of the equipment and machines for the fabrication purpose in any manufacturing business. The nature of PFM is dealing with the management of all of the facilities that are utilised to produce products. The significance of PFM originated from the necessity of preventive maintenance of existing production facilities because as Todd (1995) stated:

- *"The mechanical parts gradually wear out"*
- *"The longer they are in use, the greater the wear"*
- *"Eventually, the point is reached where the machine ceases to operate properly because one or more of the parts has worn too far"*
- *"The objective of maintenance is to replace the part just before the point where failure is increasingly likely to occur"*

- *"The operating age at which the probability of failure starts to increase significantly can be estimated by analysis of past failures, or by comparison with similar parts in other equipment"*

- *"Any difficulty in estimating the operating age at its breakdown point can be compensated by increasing the frequency of maintenance inspection"*

As a whole, the management of existing facilities involves many decisions to be made rather than the maintenance of the facilities only. The activities within PFM should include maintenance, enhancement and replacement. Traditional facilities management may focus on maintenance without linking them into the strategic concerns. In reality, the dynamic changes of the customers' requirements on the products might influence the strategic objectives of the company for survival, and the trade-off of the strategic objectives will affect the management of existing facilities. Maintenance goals and strategies constitute one of the most important components of the PFM framework but they should be formulated to support the corporate strategy and business drivers that constitute the critical success factors of the firm (Jonsson, 1997). The aim of PFM is to support the strategic objectives of the company and enhance the competitiveness of the products. The competitiveness means to satisfy the competitive criteria in terms of quality, delivery reliability, delivery lead time, flexibility, cost and price. The modern PFM framework should be an integration of manufacturing strategy, facilities maintenance, facilities performance measurement, and management of the production requirements.

2.3 Manufacturing Strategy Formulation

The role of strategy is to provide direction to an organisation and channel its resources in the most productive directions, the goal being to achieve a sustainable advantage over competitors (Hayes *et al*, 1996). Since Skinner (1969) pointed out the missing links between the manufacturing functions and strategy within American firms, manufacturing strategy or what is also called operations strategy has grown rapidly. More than once, Skinner (1969, 1974, and 1996) argues that the use of manufacturing in corporate strategy as a management practice is not widespread enough. The management of production facilities and equipment is considered to be one of the critical elements in his formulation of manufacturing strategy. He also pointed out that what appear to be routine manufacturing decisions will frequently limit the corporation's strategic options. Poor decisions about facilities, equipment, personnel, and policies, may take years to turn around.

Hayes and Pisano (1996) observed that one of the key factors behind Japan's success is that Japanese companies have a clear, inter-linked and holistic integration from marketing to manufacturing. Manufacturing strategy is not just about aligning operations to current competitive priorities but is also about selecting and creating the operating capabilities a company will need in the future.

The purpose of the manufacturing strategy formulation process is to identify business competition focus, corporate objectives, performance measures, manufacturing aims, and initiatives. All of these items are also the targets for PFM to support. From a pragmatic implementation viewpoint, PFM is a series of activities dealing with the utilisation and future arrangement of existing facilities. The ultimate principle is to support the strategic objectives, in particular to produce products that will satisfy the competitive requirements. There is a need to clarify the manufacturing environment, external drivers, strategy and internal manufacturing response. In the practical world, Jonsson (1997) surveyed 284 Swedish manufacturing companies and found that many companies do not have clear goals for manufacturing and even fewer have any policies for maintenance. This is serious, as strategies and goals are prerequisites for achieving more effective maintenance and consequently improving the planning and control of production facilities management.

2.3.1 Domain of Corporate Strategy

In implementing a manufacturing strategy formulating process, there is a need to understand the structure of a corporate strategy. Figure 2.2 shows the typical structure of a corporate strategy.

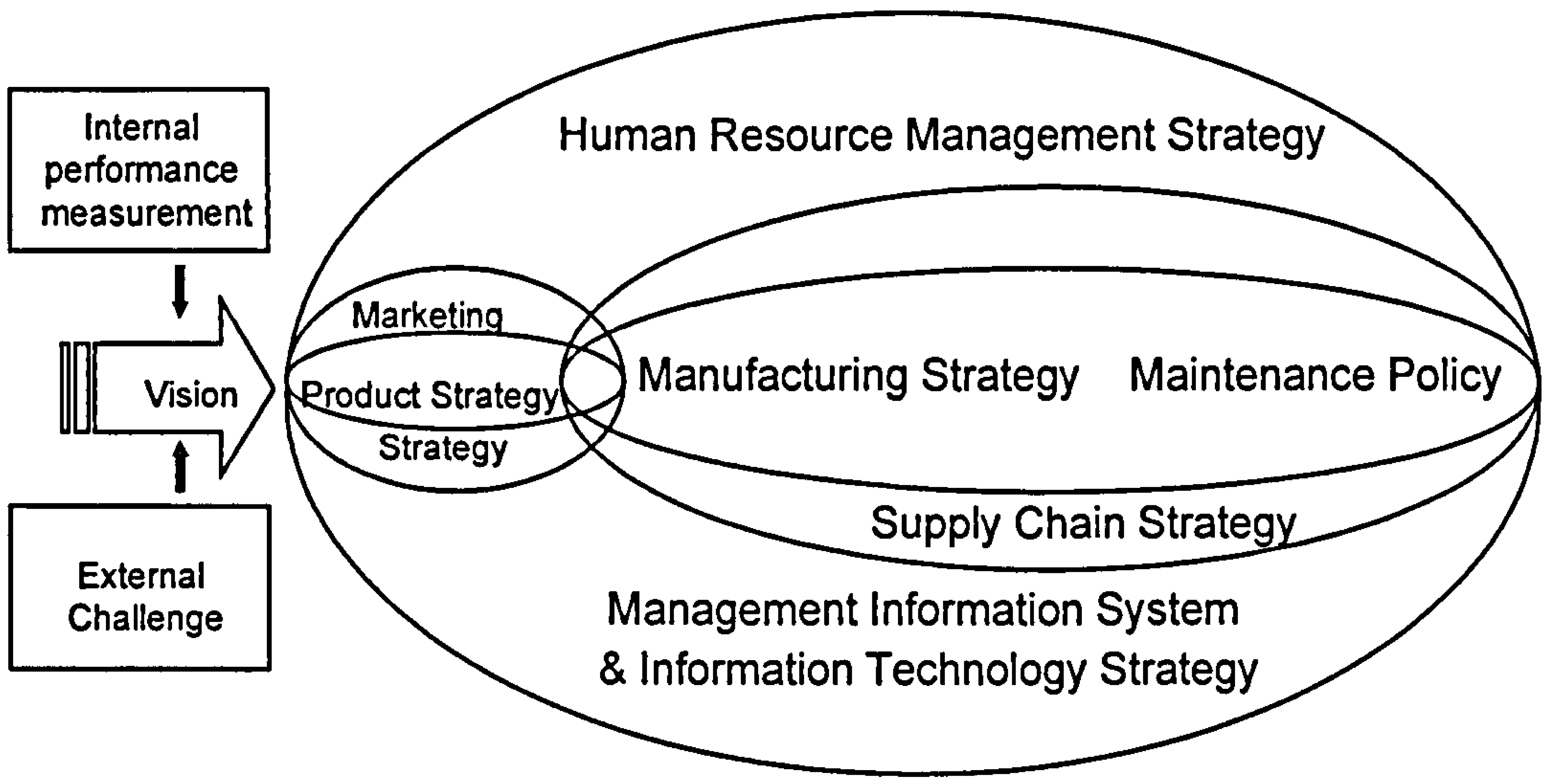


Figure 2.2 Corporate Strategy Structure Diagram
(Modified from: CSC, 1996)

The diagram proposed by CSC (CSC Computer Sciences Ltd) did not provide a detailed process for the implementation of manufacturing strategy formulation but it describes the key elements to establish corporate strategy, as follows:

- Vision: This is the expectation for future business which is generated from an analysis of the internal and external situation. The vision will be identified in terms of some strategic objectives, such as quality, delivery, flexibility, cost, and combine them with the minds of the management.

- The integration of the strategies in different levels: This covers the overall direction in the market place which also considers the issues relating to the R&D of the products and ensures that the product introduction can match the strategic objectives. This brings together the material and supply, manufacturing resources and technologies, human resource management, Information System (IS) and Information Technology (IT) application, and logistics support to serve the needs of customers.

In the CSC handbook (1996) it also stated: "*A manufacturing strategy is a particularly important segment of the overall business strategy and must be compatible with and integrate with the other strategic segments.*"

2.3.2 The Functions of Manufacturing Strategy

The function of manufacturing strategy formulation is the management of the dynamic changes in the manufacturing structure so as to create a competitive advantage and avoid a static non-response to change. As understood, the objective of manufacturing strategy formulation is to identify, quantify, and make as precisely as possible the strategically important performance objectives and the relationships between them so as to find the trade-off when they conflict with each other. In the manufacturing strategy formulation process, a great deal of system analysis, usually quantitative, is needed. There has been a substantial amount of literature written on the subject of manufacturing strategy.

Based on the previous works of Skinner (1969), Hayes and Wheelwright (1984), Swamidass and Newell (1987), Platts and Gregory (1990), Slack (1991), Slack *et al.* (1995), and Hull (1998); some of the functionalities of manufacturing strategy are:

(1) ***Manufacturing strategy is a set of coherent, unifying, and integrative pattern of decision-making processes.*** Manufacturing systems are constrained by available technologies of equipment, processes, material, and management. The manufacturing system structure must therefore be designed for its appropriate purpose. *"Choices must be made; trade-off is inevitable; one system can not be outstanding enough at meeting all criteria to create competitive advantage"* (Skinner, 1996). Therefore, focus is critical, which means to focus the entire designed system on the strategic manufacturing task, avoiding excessively broad tasks of different product/market combinations, or an unmanageably unfocused mix of products, markets, technologies, or volumes that result in excessive complexity of management.

(2) ***Manufacturing strategy contributes to achieve corporate strategic objectives.*** "*Corporate objectives are usually best expressed as customer-oriented criteria such as delivery, quality, price, and service, but may also be in strategic corporate objectives such as investment, risk, flexibility, organisational learning, and financial viability*" (Skinner, 1996).

(3) ***Manufacturing strategy defines the deployment of the manufacturing resources and their interactions with the other functions of the business.*** "*A manufacturing*

task should be set forth explicitly, describing both what must be accomplished to achieve clear competitive advantage and what facts of economics, technology, or management must be overcome in order to be successful" (Skinner, 1996).

(4) ***In formulating manufacturing strategy, the means to monitor the performance of business and manufacturing resources should be counted in.*** *"Top managers can best manage manufacturing by making certain that the structural decisions are internally coherent and focused on objectives that will create competitive advantages"* (Skinner, 1996).

Skinner recognised as early as 1969 that in order to be effective, an integrative mechanism is required between manufacturing and corporate strategy. He proposed a kind of "top-down" manufacturing strategy formulation for implementation. Many other approaches to formulate manufacturing strategy are also proposed sequentially. Here are some of them:

1. Hayes and Wheelwright (1984) proposed a "four-stage" framework.
2. Platts and Gregory (1990) proposed a "three-stage" approach.
3. Hax and Majluf (1991) proposed their conceptual framework with eight major steps.
4. Voss (1992) proposed his conceptual framework with four major stages.
5. Hill (1995) proposed a "five-stage" framework.
6. Wild (1995) proposed a "four-step" formulation process of business strategy.
7. Basu and Wright (1997) proposed an "eight step" strategic planning process.
8. Darlow (1999) investigated a number of manufacturing strategy formulation process and synthesised a "seven-step" formal planning process for manufacturing strategy formulation to capture the strategic requirements.

Summarising their approaches, the tasks contained in the manufacturing strategy formulation process include:

- ***Establishment of the hierarchical structure of the manufacturing strategy*** – Establishment of the manufacturing strategy hierarchy with three main levels of the organisation, these are the corporate level, functional level, and operational level. This is a top-down development process.

- ***Identification of the options and decision areas*** – These decisions and options to support the corporate strategy and functional strategies. This is a "bottom-up" implementation process. In 1969, Skinner mentioned seven criteria to be "traded-off" against each other, namely cost, quality, delivery cycle, investment, flexibility for volume change, flexibility for product change, and reliability of delivery promises. Because no one production system can meet all success criteria equally well a company must identify "trade-offs", its "focus" and set performance priorities.

- ***Different type and depth of the internal and external analysis*** – Different companies have different strengths and weaknesses and can choose to compete in different ways. Similarly, different production systems (the composite of decisions in a number of key decision areas) have different operating characteristics (Hayes *et al*, 1996). Therefore, rather than adopting an industry-standard production system, the "task" for a company's manufacturing function is to construct a production system that, through a series of interrelated and internally consistent choices, reflects the priorities and trade-offs implicit in its own specific competitive situation and strategy. External and internal performance analysis and SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis are the most popular techniques.

Although these conceptual frameworks are considerable, rarely are the means for collecting, monitoring, and analysis of the performance of the implementation process of the strategies discussed. This is important because without comparison, the integrated situation of the corporation can not be improved, whilst continuous improvement to cope with the changing environmental is the motto for survival.

2.3.3 Hierarchy of Manufacturing Strategy

When manufacturing strategy is considered, it is often in a hierarchical sense, contributing to the achievement of the corporate or business strategy. As with the corporate strategy, it is related to the decisions that need to made, and the deployment of "manufacturing" resources required to compete effectively (Hull, 1998).

There are three typical levels of the hierarchy of the strategy in a company, these being corporate strategy, competitive strategy, and functional strategy (or operational strategy) (Faulkner *et al.* 1995). Figure 2.3 illustrates the hierarchy of the manufacturing strategy in a company (DTI, 1993). This hierarchy highlights that the manufacturing environment is an integration of different functional activities from different departments. These activities have mutual influence. The process of formulating a manufacturing strategy should take the factors of external drivers and internal support from all functional departments into an integrated consideration. To satisfy the customer requirements is always the central aim of the corporate strategy. The concept of the hierarchical structure of the strategy can also be found in the earlier approaches of Hayes and Wheelwright (1984), and Hax and Majluf (1991).

Manufacturing environment -External drivers, strategy and Manufacturing Response

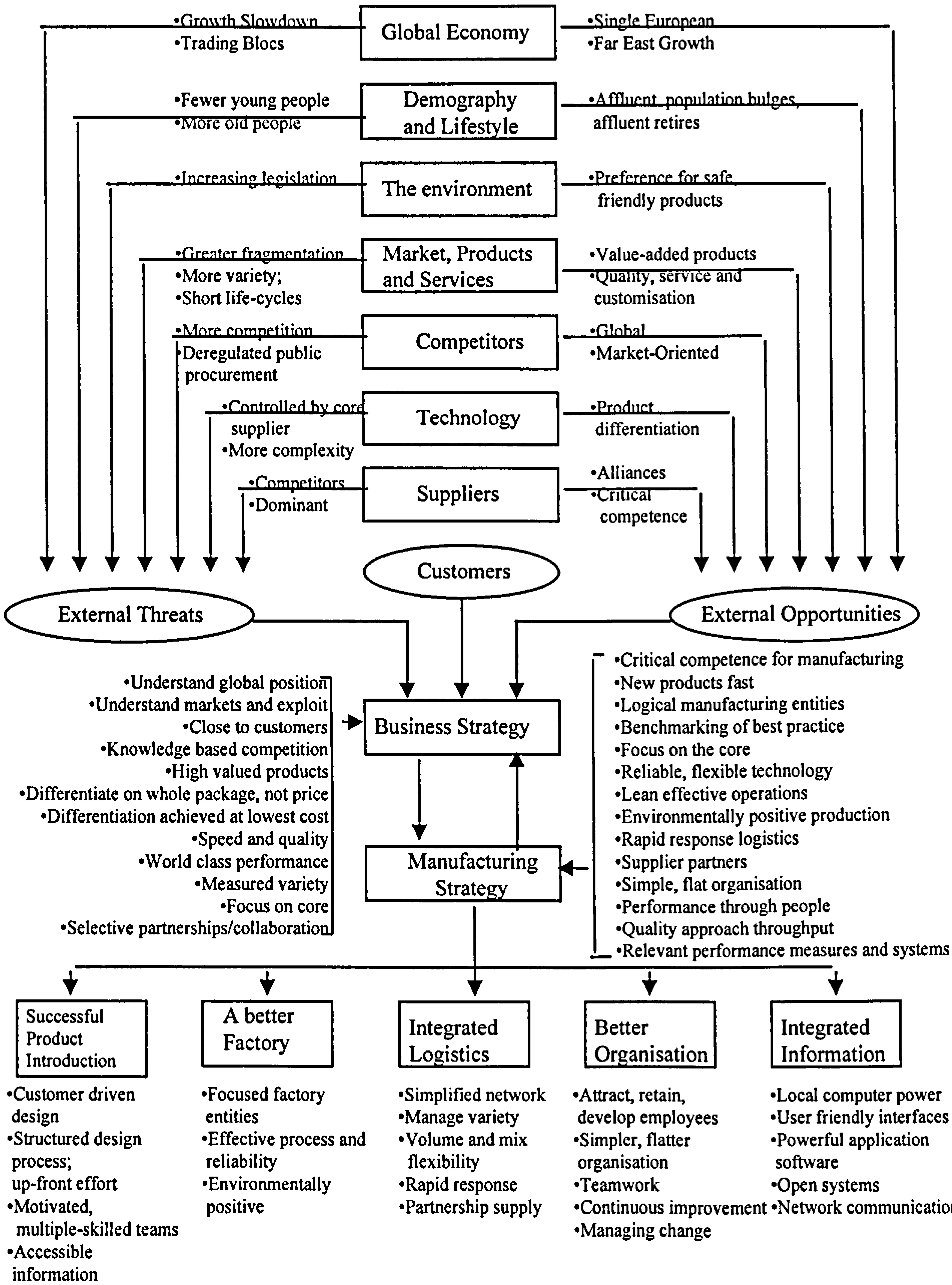


***Figure 2.3. Manufacturing Strategy Hierarchy – External Drivers, Strategy and Manufacturing Response** (Source: DTI, 1993)*

2.3.4 The Decision Areas in Manufacturing Strategy

Manufacturing strategy is composed of strategic policies in different decision making areas. Table 2.1 depicts the decision-making areas proposed by several researchers.

Table 2.1. Manufacturing Strategic Policy Areas of Different Approaches (Source: Hull, 1998)

Skinner (1974)	Hayes & Wheelwright (1984)	Buffa (1984)	Fine & Hax (1985)	Hayes, Wheelwright & Clark (1988)	Platts &Greggory (DTI, 1988)	Roth, Giffi & Seal (1990)	Hax & Mailuf (1991)
	Capacity	Capacity	Capacity	Capacity	Capacity		Capacity
Plant and equipment	Facilities		Facilities	Facilities	Facilities	Manufacturing capabilities	Facilities
	Technology	Product / process technology	Processes and technologies	Production equipment and systems	Processes	Technology	Process technologies
	Vertical Integration	Position of production system			Span of process		Vertical integration
		Strategy with respect to suppliers / vertical integration		Internal / external sourcing	Suppliers		Supplier relations
Labour and staffing	Workforce	Workforce and job design	Human resources	Human resource policies	Human resources	Human assets	Human resources
	Quality		Product quality	Quality systems	Quality	Quality and customer	Quality management
Production planning and control	Production planning and control	Strategic implications of operating decisions		Production planning	Control policies		
Product design / engineering			Scope of new products	New product development	New products		Product scope and new products
				Performance measurement systems		Performance measurement	
Organisation & management	Organisation			Organisation		Organisation	Manufacturing organisation

Skinner (1974)	Hayes & Wheelwright (1984)	Buffa (1984)	Fine & Hax (1985)	Hayes, Wheelwright & Clark (1988)	Platts &Greggory (DTI, 1988)	Giffi, Roth & Seal (1990)	Hax & Mailuf (1991)
						Management approach	
						Manufacturing strategy	

Based on the reviewed literature, to formulate a manufacturing strategy comprehensively, the following decision areas should be covered. The significance of each area is:

- ***Capacity:*** The size, timing and type of capacity, including policies for demand variations and long term trends and bottlenecks.

- ***Facilities***: The size, location, specialisation and organisation of production facilities, both external and internal, including policies for focus and complexity.

- ***Processes and Technology***: The arrangement of the plant and the type of equipment, including policies for process, volume decisions, flexibility, capability, automation, focus and dedication, etc.

- ***Vertical Integration:*** The position and possession of the supply chain and direction of future expansion or contraction, including make-or-buy policies and market mechanisms.

- ***Supplier Relations***: The types of relationships with internal and external sources, including suppliers, degrees of co-operation and competitiveness, performance measurement and controls.

- ***Human Resources***: The selection and training of employees, skill levels, remuneration policies, quality, performance and appraisal issues, motivation and job satisfaction.

- *Quality System*: The implementation of quality assurance and control, capabilities, improvement programmes and responsibility.

- *Production Planning and Control*: The degree of centralisation, control structure, planning, scheduling and expediting, prioritisation and material and information flows.

- *Product Scope and New Product Introduction*: The scope and range of products, the rate, mode and policies for product introduction, life cycles, innovation and communication.

- *Performance Measurement*: The degree of focus on competitive variables, including reward systems and capital allocation.

- *Organisation*: The structure and design of the organisation, including culture, hierarchies, authority, formality, responsibilities, centralisation, openness and management approach.

2.3.5 Standardisation of the Manufacturing Strategy Formulation and Implementation Process

With respect to a quality management system, standardisation is a vital method of improving a company's quality, productivity and competitiveness (Dahlgaard, 1998). In relation to ISO 9000 and other international standards, it is apparent that although standards may be set in various ways they are a must. As Greenhalgh (1991) stated, a structured and formated implementation document would provide at least the following benefits:

1. It provides a practical way of thinking about strategy.
2. It stresses direction and focus.
3. It flows naturally from the analytical stage.
4. It leads easily into the operating plan.
5. It is an instrument of communication.

In standardising the formal planning process of manufacturing strategy formulation, Hull (1998) accomplished a more comprehensive investigation into the implementation process of formulating manufacturing strategy and looked into the issue of the interface issues between these strategic objectives and the steps to generate the improvement initiatives with an associated implementation workbook. Hull's study was focused on the interface of manufacturing system analysis and manufacturing system design whilst it is not detailed enough to link the implementation process to monitor the operational performance during manufacturing system operation. There is still the lack of a tool for the implementation to link production facilities performance and strategic objectives. However, his development of an associated implementation workbook highlights the advantage of standardised documents which can help users in the practical implementation which has been proven through the case studies in his research.

2.4 Maintenance Strategy and Maintenance Management Practices

Maintenance of existing facilities may be the first priority in a PFM framework. Maintenance is defined as: *"All activities necessary to restore equipment to, or keep it in, a specified operating condition"* (Pintelon, *et al*, 1992). Nowadays, the growing need for more intelligent management of our physical resources is one of the greatest challenges facing business and government managers (Ahlmann, 1984). Every industry should devote as much planning and development to the maintenance function as to production, product research, marketing, etc. but it is not the case. One of the many reasons is the lack of a common language when top management meet the maintenance engineer (Ahlmann, 1984) and maintenance management of industrial equipment is an important but still relatively neglected business function (Pintelon, *et al*, 1992; Kelly, 1997).

2.4.1 The Impact of Maintenance in Manufacturing Industry

The importance of reliability and maintenance has long been understood by aircraft operators and by the military in general. However, it is only relatively recently that the reduction of life cycle costs through maintenance has received close attention from manufacturing managers (Greenough, 1999). In a benchmarking study of Scandinavian and US manufacturers, Luxhoj, *et al* (1997) stated that many manufacturing organisations now realised the critical need for effective maintenance of production facilities. The results of the study identify two major trends in maintenance management. They are:

1) The emergence of advanced maintenance technologies and methods, such as expert systems and condition monitoring.

2) The linking of maintenance to quality improvement strategies and the use of maintenance as a competitive strategy.

Experience gained in leading manufacturing companies by researchers (Labib, *et al*, 1996, 1998) has shown that formulating a maintenance strategy is a difficult process with many problems. It often suffers from the lack of a systematic and consistent methodology, and satisfying all the many different interested parties – while at the same time achieving the objectives of the company - becomes an almost impossible task. As a result, maintenance strategies are formulated in an iterative way, involving different decision makers and multiple objectives (such as achieving high productivity, availability, and quality – subject to availability of spares, manpower and skills and to meeting the constraints of the production plan). Labib, *et al,* (1996) also pointed out that general procedures for formulating strategy have not been widely used by maintenance practitioners. Some manufacturing strategy formulation proposals have not included maintenance processes as well (Platts and Gregory, 1990; Voss, 1992; Hill, 1995). To implement an effective PFM, there is a need to integrate facilities maintenance to the manufacturing strategy.

Maintenance evolution started from the early days of machinery, when repairs were carried out only when the machines ceased to work. Then came the advent of preventive maintenance, where parts were replaced to ensure breaks did not occur. Present day strategies have advanced to the stages of Reliability Centred Maintenance (RCM) and Total Productive Maintenance (TPM) in a search for optimisation of existing facilities. From the reviewed literature, the majority of manufacturing companies still operate a breakdown (reactive) maintenance regime. However, the maintenance function is now expected to offer higher plant availability and reliability, greater safety, better product quality, longer equipment life, greater cost effectiveness and no damage to the environment (Weet, 1999a and 1999b). This argues that the new maintenance plan should be linked with strategic concerns.

The efficiency and effectiveness of existing facilities rely on the integration of a specified business and maintenance policy, disciplined workforce, and constant collection of historic operation data. Traditionally, maintenance activities were based on reactive, fire-fighting, corrective maintenance approaches, or on Planned Maintenance (PM) practices that mainly take the form of equipment overhaul or item repair, item replacement at fixed intervals (Smith, 1993; Boznos, 1997). The trends away from the labour-intensive to the computer-controlled intensive production and from manufacturing for stock to Just-In-Time manufacturing have made efficient maintenance a key function. Maintenance is a competitive weapon for manufacturing (Basu, 1997). Nevertheless, a downtime survey by Gould in 1996 indicated that around one third of UK manufacturing companies were taking a 'laissez-faire' stance on downtime and not taking significant steps to address the associated problems. It also concluded that reduction of production downtime is a strategic business issue which has a major impact on the bottom line. Lack of understanding of the real cost of production downtime and failure to adequately address the problem led to poor line efficiency.

Since the 1980s, more and more researchers reported that due to the huge increase in the number and variety of physical assets (plant, equipment, and buildings), maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. Maintenance is responding to changing expectations (Moubray, 1997; Kelly, 1997). These include a rapidly growing awareness that the maintenance objective should be compatible with the corporate and production objectives such as safety, product quality, plant availability, cost, etc. Effective strategies deliver plant reliability and good maintenance emphasises the need to consider plant reliability within a wider context of corporate and production objectives (Bates, 1996).

2.4.2 Total Productive Maintenance (TPM)

TPM (Total Productive Maintenance) is one of the methodologies for the management of existing facilities which was first introduced to Japanese Industry in 1971 by Seiichi

Nakajima. Nowadays, TPM has become one of the main streams in maintenance management methodologies. Dependable, effective equipment is a must to establish lean manufacturing (Sekine and Arai, 1998). When equipment has a history of breakdowns and defective operation, a plant must input excess work-in-process and prepare excess inventory for the unpredictable accident. When minor stoppages eat into the production schedule, extra labour hours are required for catching up.

Ideally, TPM covers most aspects of manufacturing operations on the shop floor, including (Nakajima, 1988; Davis, 1992; and Greenough, 1999):

1) ***Simple 'good housekeeping' activities (5Ss)*** – Roughly seiri (organisation), seiton (tidiness), seiso (purity), seiketsu (cleanliness), and shitsuke (discipline).

2) ***Operator or 'first line' maintenance*** – Autonomous maintenance by operators.

3) ***Continuous improvement groups*** - total participation for TPM implementation

4) ***Measuring equipment effectiveness and improving effectiveness (Measuring and eliminating the six big losses)*** – equipment loss (such as breakdown of equipment), set-up and adjustment losses (such as die change), idling and minor stoppage losses (such as abnormal operation of sensors), start-up and shutdown losses (due to unstable conditions during start-up), reduced speed or capacity losses (deviation between designed speed and actual operation speed), and quality defects or rework losses (scraps and rework of defective products).

5) ***Maintenance systems and techniques*** – for preventive maintenance.

6) ***Specify new machinery*** – equipment redesign for easy maintenance implementation.

TPM is not only a maintenance initiative or improvement programme but a strategic operational strategy.

In implementing TPM, continuous monitoring of equipment performance and selection of appropriate monitoring measures are the key activities and the measures for this monitoring purpose is useful for PFM to be discussed. The basic conditions related to the performance of the equipment of the future are development, reliability, economics, availability and maintainability. Collection and analysis of historic maintenance data related to these requirements is necessary for the improvement of facilities management. However, often the technical improvement data gathered by the maintenance engineers during the daily preventive maintenance activities – data that can improve reliability and maintainability – are never put to use (Gotoh, 1991).

In PFM, Gotoh (1991) proposed that the best stage to decide the performance of equipment is during its design stage and he recommended early equipment management. Maintenance engineers sometimes failed to organise and present to the design engineers the technical data relative to the reliability or maintainability that should be considered at the equipment design and fabrication stages. Sometimes the equipment designers themselves failed to gather, organise, and use similar technical data.

Maintenance engineers must not only supply maintenance data as feedback to the design engineers, they should also actively support the design engineers. The design engineers in turn should take greater responsibility for the equipment they design by keeping track of the life cycle of such equipment. The design engineers should then be better prepared to develop technical solutions to the various issues that appear in the equipment after they are running.

The advantage of TPM is that it focuses on operation and maintenance management as a whole, and develops performance indicators for the assistance of monitoring the performance of equipment. In reality, TPM has been proven to be successfully utilised in the automotive industry (Greenough, 1999). Merging the initiatives embeded in TPM with strategic concerns will enhance the comprehensiveness of managing existing facilities; in particular, the performance measures to monitor the six types of equipment loss provides guideline for the establishment of a PFM Performance Measurement System (PFM PMS).

2.4.3 Reliability Centred Maintenance (RCM)

Reliability enhancement may be the target of maintenance in the future. Penrrous (1999) stated that *"The future for asset management could be more about 'designing out'* *problems than dealing with them when they occur. According to those in the know, Condition-Based Maintenance (CBM) is where it is at now, but designing for reliability and maintainability is where it is going."* This viewpoint reinforces the skill and commitment of both production and maintenance staff and is complementary to the continuous improvement requirement. What it means in practice is that those who have to operate plant and machinery should be involved at the procurement stage so that their experience can be contributed. By taking such experiences into account, it is possible in many conditions to design greater reliability into equipment.

RCM research and implementation is another methodology for the management of existing facilities which was started with the publication of the United Airlines report by Nowlan and Heap in 1978. Figure 2.4 shows their observation results.

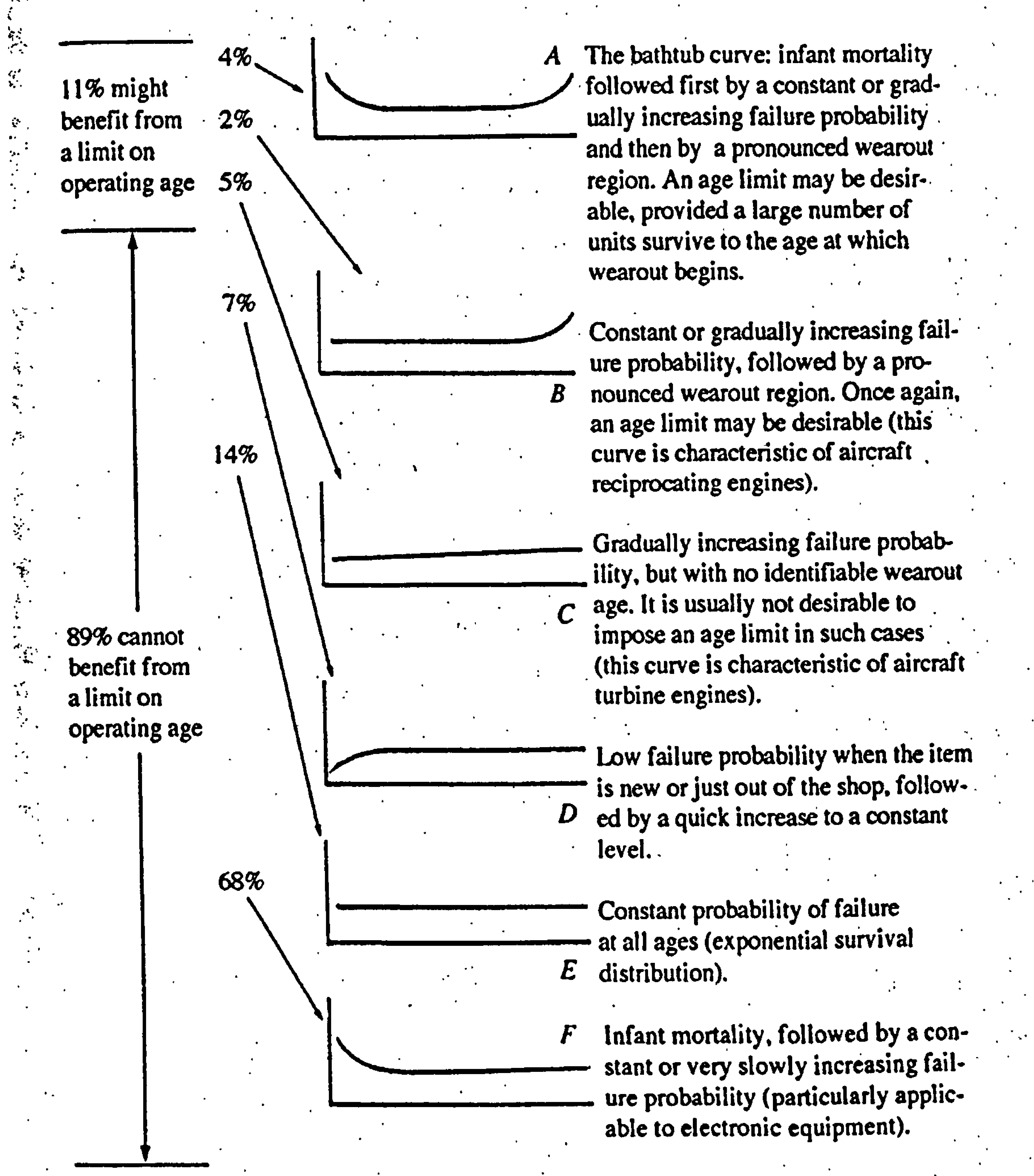


Figure 2.4. Age-reliability Patterns

(Source: Todd, 1995, reproduced from Nowlon and Heap, USDoD REPORT No. AD-A066-579, December 1978)

The graph shows the conditional probability of failure against the operating age for a variety of electrical and mechanical items. These findings contradict the belief that there is always a connection between reliability and operating age. The RCM has been proven to be useful primarily in the aviation industry in the beginning to determine scheduled maintenance policies for civil aircraft. Briefly, it is a structured methodology and a unique process, formulated via a structured framework of analysis aimed at ensuring the attainment of a system's inherent reliability, i.e. the reliability that it was designed to attain. This kind of analysis has since been adapted for the manufacturing and process industry as an evolutionary approach to equipment reliability as well. Also, the structured framework can be utilised to develop optimum equipment maintenance plans and strategies.

The RCM process, as now developed, has three key features (Knezevic, 1997):

1) It recognises that the inherent reliability of any item (including any facility) is governed by its design and how it is made, and that no form of maintenance can yield reliability beyond that inherent in the design. An RCM analysis starts by defining the desired performance of each plant in its operating context and ascertains whether the inherent reliability is such that maintenance can deliver that performance. If it can not, it highlights the problems which are beyond the scope of maintenance and need further action such as redesign, modification, change in operating procedures or raw material change.

2) RCM recognises that the consequences of failure are far more important than their technical characteristics. A structured review of the consequences of failure focuses attention on the failures which most affect the safety and performance of the plant.

3) RCM incorporates the latest research on equipment failure patterns into a sophisticated decision algorithm for the selection of preventive maintenance tasks, or the actions which should be taken if no suitable tasks can be found. The approach recognises that all forms of maintenance have some value in any situation.

Based on these principles, the strength of RCM is that it recognises that the reason for doing any kind of proactive maintenance is not to avoid failures but to reduce the consequences of failures. The driving element in all maintenance decisions is the consequence of the failure for the equipment as a whole.

The purpose of RCM is to preserve a system's function (Smith, 1993). Therefore, RCM is focused on the needs of the asset, not the shape of the organisation (Kelly, 1997). The implementation of the RCM approach is based on the principle that no preventive maintenance task will be performed unless it can be justified (Knezevic, 1997). The RCM process consists of inspecting the way equipment fails, and choosing the correct maintenance action to ensure that the desired overall level of plant performance (i.e. availability, reliability) is met (Boznos, 1997).

The advantages of RCM are to identify the failure modes and priortise the maintenance tasks. Nowadays, RCM is one of the main streams of maintenance management methodologies, a large number of interpretation and variations of RCM analysis, decision logic, and processes have been developed, such as Smith's seven steps (Smith, 1993), Knowles's seven steps (Knowls, 1995), Moubray's eight steps (Moubray, 1997) and Kelly's six step structure of RCM (Kelly, 1997). With the focus on the aim of reliability, RCM has been successfully achieved in the aviation industry. However, RCM is not so popularly accepted by industries other than aviation. Kelly (1997) and Wireman (1998) surveyed some unsuccessful companies who had difficulty in implementing RCM. The most important barrier is that the implementation of RCM will need much greater resources of time and manpower for data collection and analysis work than had been anticipated. Some other barriers which prohibit the success of RCM have been investigated (Wireman, 1998). These are:

1. Insufficient equipment failure data
2. Poor results in Preventive Maintenance (PM) and Predictive Maintenance (PdM) efforts
3. Poor training in the RCM methodology
4. Lack of organisational buy-in
5. Insufficient staffing for the problem
6. Reactive or instant RCM results

7. Short-term equipment focus

8. Poor organisational discipline.

Nevertheless, the contribution of RCM to PFM knowledge is that it incorporates several basic techniques of reliability engineering with the development of techniques in failure mode analysis which has proved to be useful. In comparison with TPM, RCM better addresses the technical characteristics of a production system and TPM aims to more effectively manage the human aspects. Therefore, manufacturing companies should adopt a maintenance strategy that integrates both RCM and TPM. In particular the measures developed for the monitoring purpose by their concepts in order to achieve better PFM should be included.

2.4.4 Business Centred Maintenance (BCM)

BCM was coined by Kelly in 1998 whose aim was to research a methodology or guidelines for deciding maintenance objectives, formulating equipment life plans and plant maintenance schedules, designing the maintenance organisation and setting up appropriate systems of documentation and control. The optimal maintenance strategy for industrial plants is driven throughout by the identification of primary business objectives and their translation into maintenance objectives, and the organisational design, the maintenance and production departments being inseparable, therefore it is termed Business-Centred-Maintenance (BCM).

BCM springs from the identification of business objectives, which are then translated into maintenance objectives and therefore completely underpin the strategic formulation. The methodology for developing maintenance strategy in BCM is outlined in Figure 2.5.

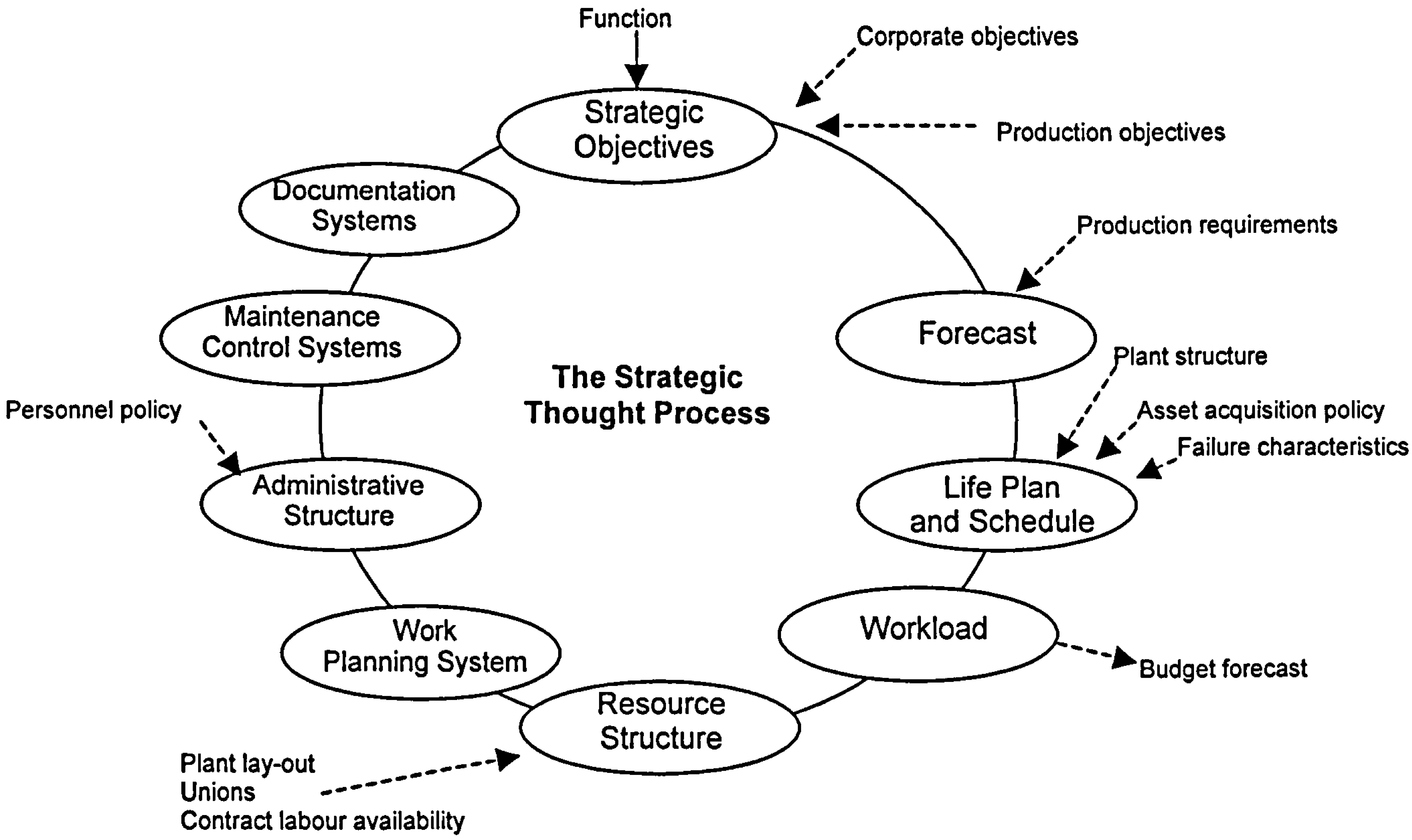


Figure 2.5. Business-Centred Maintenance Model
(Source: A, Kelly; 1998)

The concept of BCM is that the best time to influence maintenance and unavailability costs is before the plant comes into use, and is hence within the strategic decision making field.

In implementing BCM, a control system is needed to ensure that the maintenance effort is achieving its objectives and to provide corrective action if it is not. The functions of the control system are:

- Control of the overall maintenance effort: Ensuring that the budgeted levels of maintenance effort are being sustained and that required plant output is achieved.
- Control of maintenance effectiveness: Ensuring that life plans are effective in controlling plant reliability.

- Control of maintenance organisational efficiency: Monitoring utilisation of workforce, material and tools.

Purchase of new or replacement plants should be based on a present-value life-cycle analysis of costs which should consider both maintenance and unavailability costs, these being estimated from documented experience. The company should set up a system to record and analyse plant failures and identify areas of high maintenance cost. Within the organisation, a facilities management system should be defined and established. This should transcend traditional functional boundaries for decision making and will require commitment from the senior management. This highlights the necessities that maintenance strategy should be strategically driven and a well-structured performance measurement system is required in achieving PFM work.

2.4.5 Computerised Maintenance Management System (CMMS)

In facilities management, it is imperative to handle historic operational data from different facilities locations simultaneously. The bigger the organisation, the more complicated it is to collect and analyse useful information from them. With powerful and cheaper processing power, the Computerised Maintenance Management System (CMMS) has been available from the late 1970s and is now common in the manufacturing industry (Eason, 1997). The CMMS is, in reality, a computerised version of a maintenance information system. In theory, the CMMS should make maintenance faster, make it easier to collect data and then manipulate it into a meaningful report format. In reality, the need for appropriate maintenance software is growing rapidly as well. "*The maintenance management market will exceed £918M by the year 2001 and currently totals £437M, according to estimates by International Data Corporation (IDC) and Automation Research Corporation. Its growth is out-pacing that of the overall software market*" (PSDI, 1999).

In dealing with the key elements of a CMMS, Figure 2.6 highlights the basic components of it.

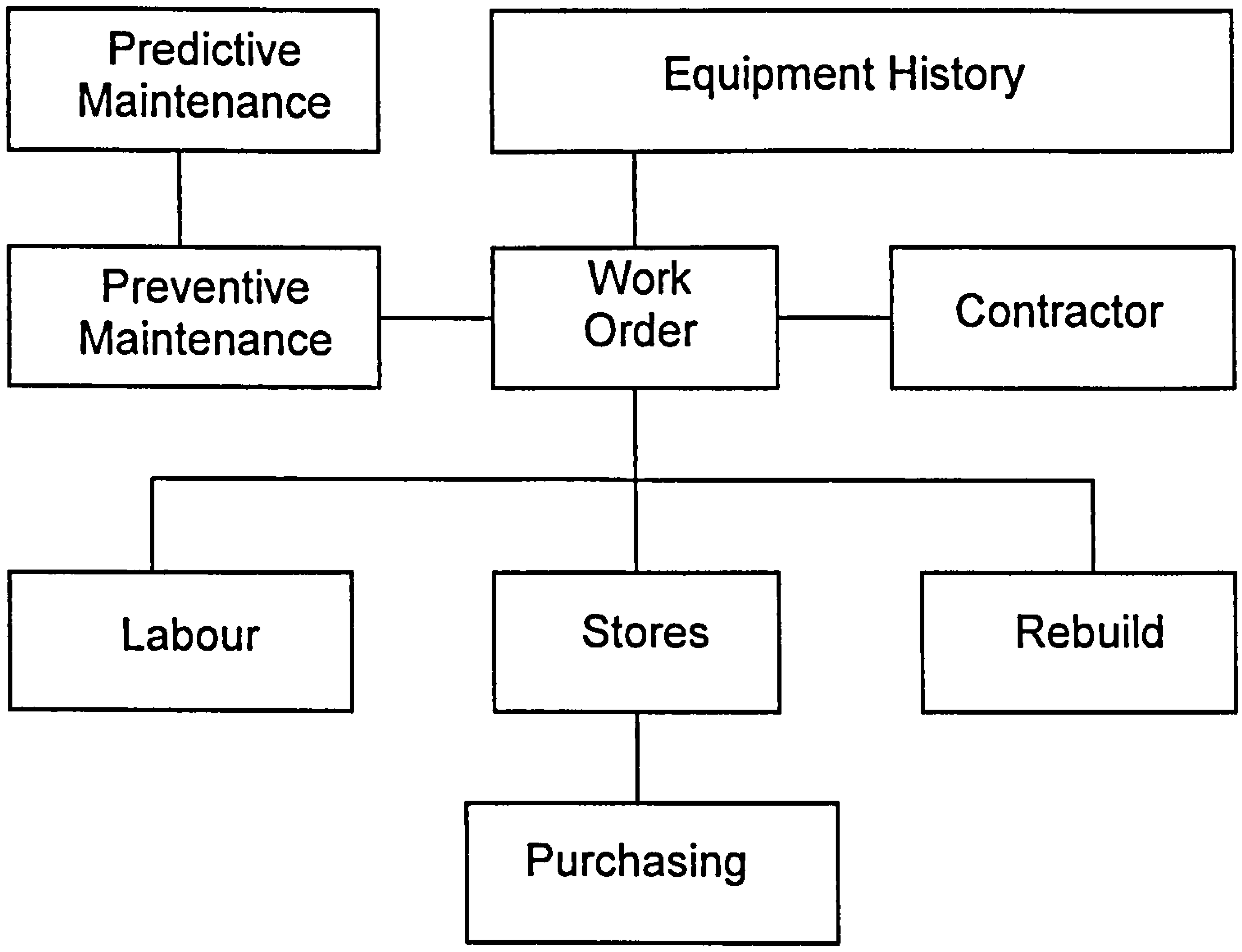


Figure 2.6. Basic Components of a CMMS
(Source: Wireman, 1998)

The work order is the key feature of the system. It collects all the labour data, material data, contractor data, and preventive maintenance data that is written against a piece of equipment. The information collected is then stored in a database called the equipment history, where all of the data is drawn to produce all of the reports needed by the organisation to manage the equipment or assets (Wireman, 1998). The CMMS software is developed to solve some obvious and pragmatic issues:

- To reduce downtime, by accurately identifying why, when and where problems are occurring.
- To reduce costs, by identifying where resources are being used.
- To increase safety, by maintaining on a regular controlled basis.
- Quality system compliance. Giving the ability to show where and when maintenance work has been carried out.

- Control. A hidden benefit of CMMS is that the manager will become much more aware of both production requirements and resources. This awareness helps to create a more professional "switched-on" feeling amongst both management and workers.

Therefore, a CMMS can help production facilities management in three main ways:

1. ***Information resources***– holding easily accessible data on plant, facilities and their work performance.

2. ***Work processing and control***– keeping track of what work needs to be done, what work is in progress and what work has taken place.

3. ***Reporting and analysis*** – using information recorded in the system to help report the performance and make decisions, for example when to replace a piece of equipment rather than maintain it.

However, there is evidence that such systems have often failed to deliver the expected benefits. In an analysis of 725 maintenance management audits carried out on behalf of the DTI in the U.K. over 60% of companies were not satisfied with their MMIS (Maintenance Management Information System) (Greenough, 1999). The common reasons are:

- CMMS is designed by people with insufficient experience of maintenance management (Raouf *et al*, 1993).

- Absence of clear maintenance strategy – In the aforementioned analysis, 85% of the companies audited did not have a clear maintenance strategy. This result shows if there were such a strategy, it would be supported by the CMMS used (Greenough, 1999).

- Lack of sufficient and effective training and a failure to address the fear of using computers (Jones, 1994).

In the application of CMMS, the part of "resource planning and control" is very much a background activity but can have a major impact when things go wrong. It is a complicated activity which considers many more parameters than can be handled simultaneously by any means of human intervention. To any software developer, this part is always left to the user to make timely decisions based on hard facts rather than supposition (MTAS, 2000). From the viewpoint of consistency, the decision-making of these parameters should match the strategic objectives of the company. In implementing PFM work, the consistency of the strategic requirements from the corporate level down to the operational level is always one of the key factors to be concerned.

2.4.6 Terotechnology

"Terotechnology" was coined in the U.K. in 1970. The British Standards Institution defined it as: "*A combination of management, financial, engineering, and other practices applied to physical assets in pursuit of economic Life Cycle Costs (LCC)*" (Husband, 1976). More recently, Nakajima (1988) stated "*Its practice is concerned with the specification and design for reliability and maintainability of plant machinery, equipment, buildings, and structures, modification, and replacement, and with feedback of information on design, performance, and cost.*"

The fact that "Terotechnology " is virtually unknown in manufacturing today is testimony to the failure of this DTI initiative. However, the initiative of Terotechnology is creative whilst it needs more research on the implementation of the integration of these separate practices applied to asset management. Its goal of integration of management, financial, engineering, and other practices applied to physical assets in pursuit of economic Life Cycle Cost (LCC) might be workable once the appropriate CMMS and MIS (Management Information System) are applied. Also, it highlights the importance of linkage between strategic requirements (management level) and maintenance and LCC control of the operational level.

2.5. System Life Cycle Management and Integrated Logistics Support

Every product group has its life cycle in the market that typically includes market development, rapid growth, competitive turbulence, maturity and decline which will directly impact on the industrial competition and the firm's major competitors (Hayes, 1984). A facility, much like a product, goes through a life cycle. The facilities life cycle consists of four stages: design and start-up, progressive expansion, maturation and reinvestment, and renewal or shutdown (Hayes and Wheelwright, 1984). Understanding the market position of each product and the status of production facilities to ensure all equipment is available when it is needed by operations planners is a vital factor of a winning business (Todd, 1995 and Bates, 1996).

The life cycle of equipment has a special significance in the defense industry, where life cycle management is integrated into the field of logistics engineering management. Generic objectives of implementing life cycle management are to improve the timeliness, reduce cost and improve the quality of manufactured products and their necessary support from engineering, designing, and maintenance perspectives. Achieving these objectives will lead to improved operational performance and industrial competitiveness. Many conceptual frameworks of logistics management and technologies were initiated by the defence industry, whilst being prosperously applied in manufacturing industry afterwards. After all, weapon systems and equipment both possess the same characteristics that they will gradually wear-out and need maintenance, enhancement or replacement.

2.5.1 System Life Cycle Stages

Since the concept of Product Life Cycle (PLC) was developed during the 1960s, the concept of 'life cycle' has been applied in operational research as well (Hayes *et al*, 1979a, 1984; Stonebraker, 1994; Slack *et al*, 1998; and Bakers *et al*, 1999). The typical life cycle of a product or system is listed in Table 2.2. The stages contained in a life cycle are generally similar with differences in detail. The identification of life cycle stage assists the management to establish a maintenance plan and the decision-making analysis process of the implementation of the plan. In reality, it is difficult in implementation, the issue being how to quantify and clarify the ambiguity between stages.

Table 2.2. Holistic Life Cycle Stage Definition Table

Life Cycle Stage	Life Cycle Stage Approaches					
	Doyle (1976)	US Mil-STD-1388 (1983)	Blanchard (1992)	BS5760 (1997)	Froome (1997a, 1997b and 1997c)	Baker & Hart (1999)
1	Introduction	Pre-Concept	Advanced Planning and Conceptual Design	Concept and Definition	Use Study and Requirement Identification	Gestation
2	Growth	Concept Exploration	Preliminary System Design	Design and Development	Development of Equipment Concept	Introduction
3	Maturity	Demonstration and Validation	Detail Design and Development	Manufacturing	Feasibility Assessment, Designing & Production	Growth
4	Decline	Full Scale Development	Production and/or Construction	Installation	Support (Supply, Repair, Maintenance) & Performance Monitoring	Maturity
5		Production/ Deployment / Post Production	Operation and Life-Cycle Support	Operation and Maintenance	Dispose	Saturation
6			System Retirement	Disposal		Decline
7						Elimination

Study of the life cycle of the product and facility is important because in different stages of the life cycle of products and facilities, the importance of each business competitive criterion and the variety and volume of the products can be different (Hayes *et al*, 1984 and Stonebraker, 1994). The business competitiveness is reflected in terms of the competitive criteria of quality, delivery lead time, delivery reliability, design flexibility, volume flexibility, and cost. The different weight of importance of each criterion will influence the decisions of the production and facilities in each different life cycle stage sequentially.

2.5.2 The Evolution of Logistics Engineering Management

Logistics is not a new subject area but its contents are gradually evolving with changing requirements. Because systems and products today have become more complex with the incorporation of new technologies, the logistics support of the manufacturing resources to ensure they are efficient and effective becomes one of the greatest challenges facing industry (Blanchard, 1992). Historically, the concept of logistics has various significances between military and industry context. In a military sense, Webster's dictionary defines logistics as:

"The procurement, maintenance and transportation of military material, facilities and personnel" (Blanchard, 1992).

In an industrial and commercial sense, logistics is defined by the Council of Logistics Management (CLM) as:

"The art of managing the flow of materials and products from source to user. The logistic system includes the total flow of materials, from the acquisition of raw materials to the delivery of finished products to the ultimate users" (Blanchard, 1992).

From the definition, the logistics of the military viewpoint is much focussed on "system/product support" and system/equipment functionality integration. Industrial logistics is much more focussed on operational cost reduction.

More recently, the field of logistics has become much broader than initially defined and views logistics in terms of the total system life cycle so as to face the dynamically changing market. The Institute of Logistics and Transport (2000) redefined the definition of logistics as:

Logistics is the science of the time-related positioning of resource. In its most comprehensive sense, those functions which deal with:

1) *Design and development, acquisition, storage, movement, distribution, maintenance and disposition of goods*

2) *Movement of people*

3) *Acquisition or construction, maintenance, operation and disposition of facilities*

4) *Acquisition of furnishing of services*

From above definition, the essential activities of logistics should integrate transport, human relations, finance, information technology, safety, health and environment, training and education together. Based on this evolution, Christopher (1992) stated that advanced logistic management should nowadays be an integration starting from a global manufacturing strategy formulation, future ideal situation environment and current environment analysis, strategic objectives, support of different functional departments to policies and procedures of operation planning and implementation.

In implementing PFM work, to fully support logistics throughout the facilities' life cycle is as important as the maintenance of them. This requirement also highlights the incorporation of logistics management with the PFM.

2.5.3 Major Logistics Functions to System Life Cycle Management

Logistics in the context of the system life cycle involves several programme phases throughout the consuming period of this system.

More recently, limited budgets have made cost analysis more important, and decreasing budgets have made maintenance and logistics support work together to be more precisely managed. Some typical logistics problems that top management should address are:

- How to establish and maintain a dynamic logistics control system? What are those performance measures to be managed?

- How to achieve an effective integrated logistics support work, in particular, how to smooth the interface between each department and link them together?
- What is the life cycle of a product and/or system and how to make a prompt assessment of it?
- How to control the cost within a minimum base and what are the criteria to make the best decisions for the budget of the following year?
- The development and application of IT (Information Technology) is very popular and advanced, how can IT techniques support management decision and what is the implementation strategy and procedure?
- How to design and acquire a system with an IT technique that can reflect all information in a real time requirement?

It is essential that all the factors should be considered on an integrated basis. Logistics support must initially be planned and integrated into the overall system development process to ensure an optimised balance between the prime equipment and its related support. This optimised consideration includes the performance characteristics of the system, the input resources required, the effectiveness of the system and the ultimate life-cycle cost.

2.5.4 Integrated Logistics Support (ILS) and Computer Aided Logistics Support (CALS)

Integrated Logistics Support (ILS) was coined by the U.S. Department of Defense (US DoD) in 1983. CALS is known as 'Computer Aided Logistic Support', 'Continuous Acquisition and Life-Cycle Support' and also 'Commerce At Light Speed' which was first introduced by the U.S. DoD in 1987. The conceptual ILS aims to provide and sustain equipment performance (its availability, reliability and maintainability) at optimum LCC (Life Cycle Cost).

The concept of ILS brings together all aspects of support and maintenance planning, to ensure that the design and support systems are optimised. Operational effectiveness, availability, and the total costs of deployment and support are all considered. The approach is described in US-MIL-STD 1388. ILS and the associated Logistic Support Analysis (LSA), require inputs of reliability and maintainability data and forecasts, as well as data on costs, weights, special tools and test equipment, training requirements, etc.

CALS is based on the concept of ILS and especially focuses on standardisation of all the tasks of ILS with the implementation of EDI (Electronic Data Interchange) technology. The methodology taken by CALS is to use the inherent features of digitised data to revolutionise the functions of data-gathering, data storage, and data-transfer technologies associated with the development of defence systems. A key initiative is that data is going to be developed and purchased once, but can be used many times.

ILS/CALS provide a framework of principles, tools, and standards to enable good practice and the integration of information, sharing and exchange. Figure 2.7 describes the relationship between its main contents such as LSA (Logistics Support Analysis), LCC, and LSAR (Logistics Support Analysis Record).

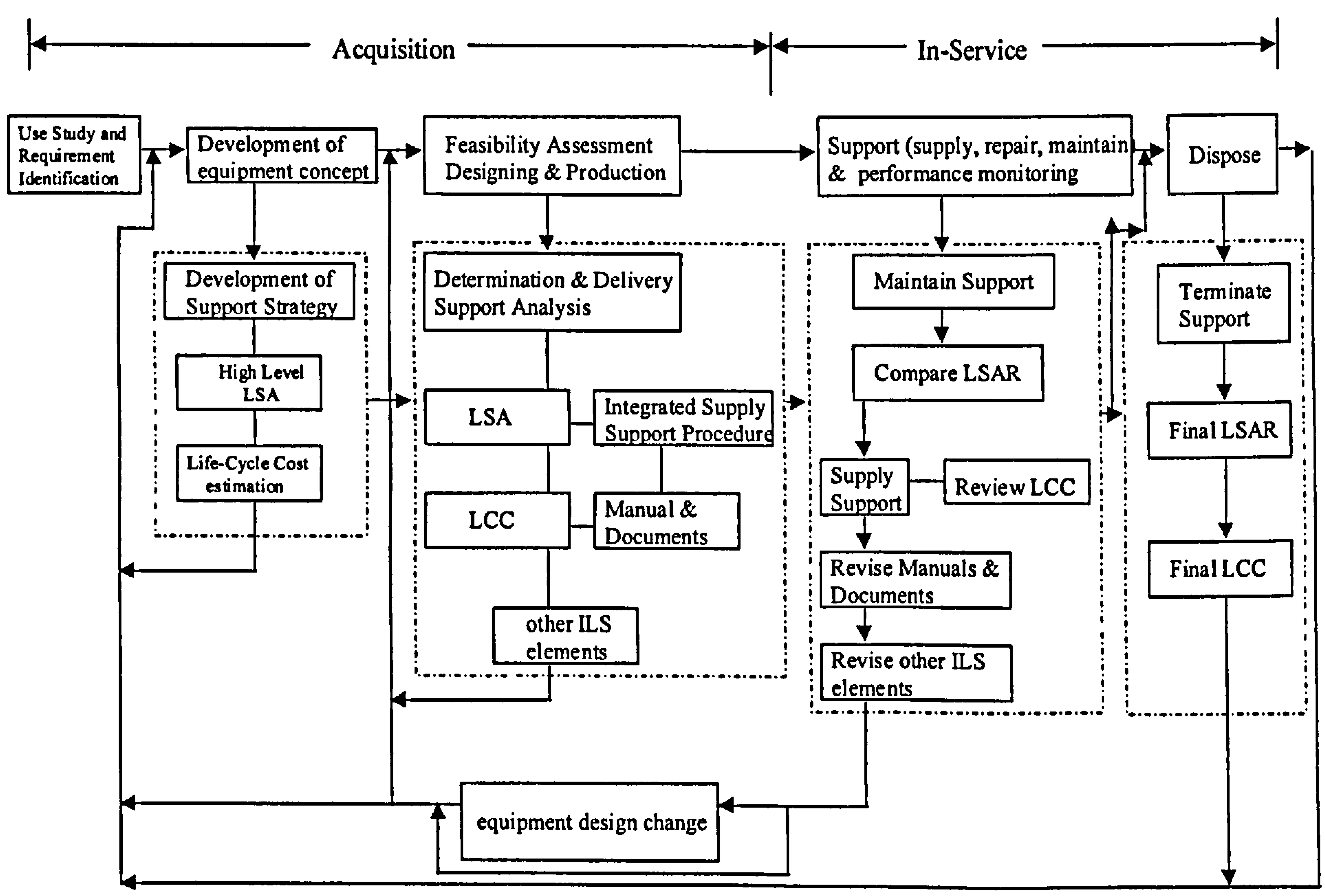


***Figure 2.7 Relationship of LSA, LCC, LSAR in ILS** (source: Galloway, 1997)*

From Figure 2.7, it can be seen that ILS is generally divided into two stages, an acquisition stage and an in-service stage and it is implemented concurrently with the equipment concept, design and maintenance supportability activities.

The purpose of use study is to detail the system description which includes the mission profile, the operating requirements, quantitative supportability factors, a description of the old system to be replaced and the existing support available for this new equipment.

In-service support of the equipment will include maintenance, spares re-supply, documentation updating and continuous configuration management. In practical application, the data will be collected and analysed on equipment performance and support consumption to compare with the original design requirements. Support performance will be measured and the LSAR will be updated through the whole life cycle of such equipment.

Actually an anticipated performance will be compared on a continuous basis. It not only affects in-service management actions but influences decisions about follow-on procurements, e.g. of the same equipment or a different modification of this equipment. In-service management decisions based on these resultant predictions, may include the need to change support facilities, spares holding, maintenance skill levels, or modification to the equipment itself. Similarly, new projects will be influenced by the analysed results of previous equipment performance as well as cost.

Disposal costs are another significant activity in ILS. These costs are considered from the equipment concept and taken into account during subsequent phases. The comparison between the actual and anticipated costs will be made to complete the historical record of the equipment.

2.5.5 Basics of Life Cycle Cost Analysis

Minimising the Life Cycle Cost (LCC) is the final target of ILS/CALS. LCC is the total cost of a product/system throughout its life cycle. LCC analysis and control is important because buying a product is not only buying the product itself but also buying the after-sales services. The issue of procurement nowadays is that the majority of companies purchase under a lowest price policy whilst ignoring in-service support. The procurement process consists of planning, designing, producing and introducing into service for a system or equipment.

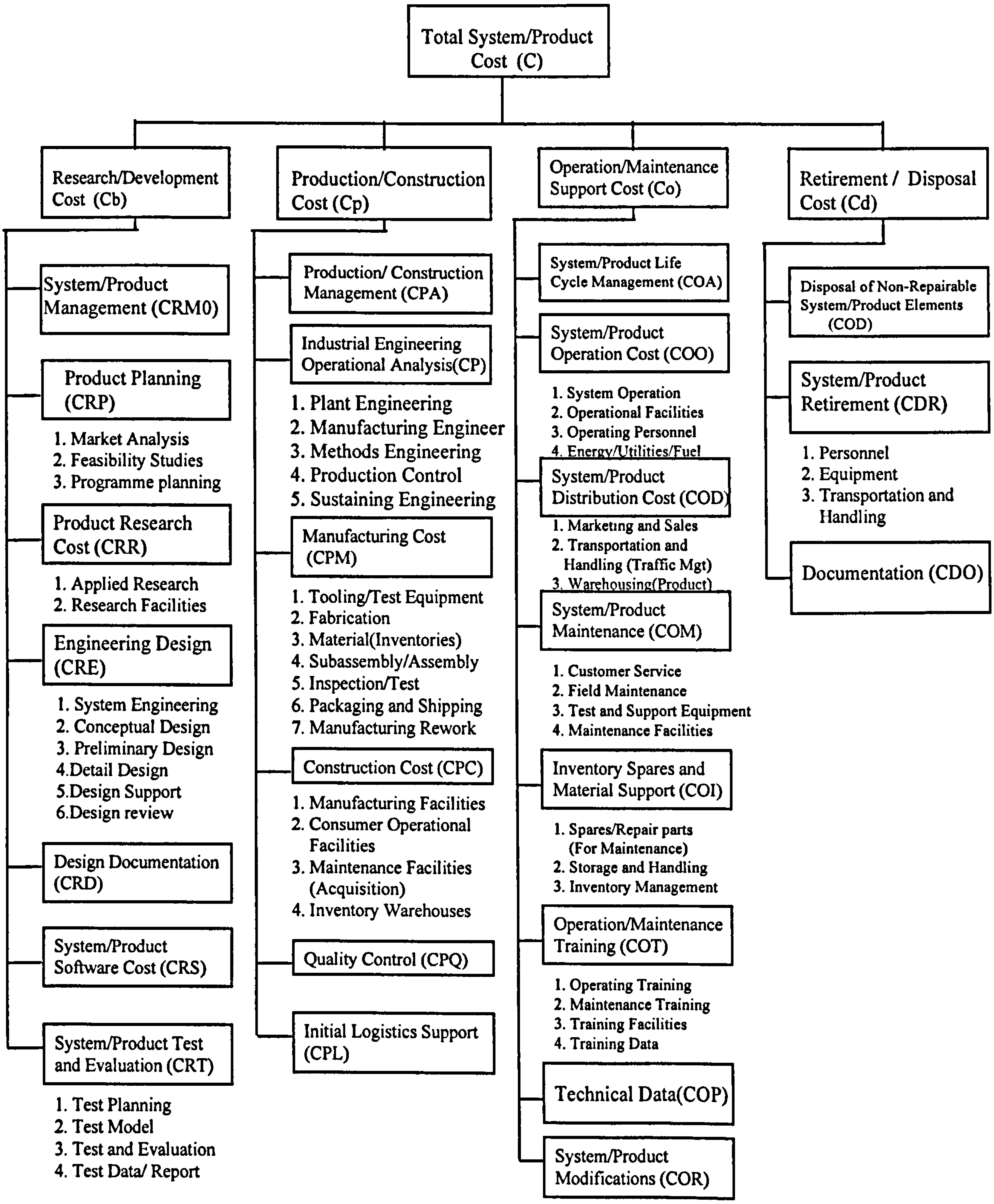


Figure 2.8 Total System/Product Cost Breakdown Structure

(Source : Blanchard, 1992)

Figure 2.8. shows a typical total cost breakdown analysis through a system/product life cycle.

Looking into the total cost analysis of facilities management, the cost of maintenance is always the highest in the total system/product cost. Experience indicates that the cost of maintenance and support activities occupies the majority of the budget. For many large-scale systems, the cost of maintenance and support is usually in the range of 60 to 80 percent of the total life-cycle cost for that system (Blanchard, 1992; Campbell, 1995; and Bates, 1996) and "*Annual maintenance cost on new equipment in U.K. was £4.3 billion*" (Bates, 1996).

In practical applications, Gotoh (1991) advocates that LCC should be integrated with TPM and make equipment life cycle planning as early as possible. In evaluating "Cause-and-Effect" relationships much of the life cycle cost can be tracked back to many design and management decisions during the early stages of the conceptual design phase. He observed that some common mistakes made in new system development or integration come from:

1. Selecting new technologies to meet performance requirements without considering system maintenance and supportability afterwards.

2. Selecting non-standard and unreliable components.

3. Packaging equipment and/or software in such a way that it can not be maintained easily.

4. Not clearly defining clear maintenance and support concepts, i.e. to define the levels of maintenance.

5. Lack of human resource ability to maintain this system work properly.

To improve these equipment planning and control issues, a well-structured PFM framework and a facilities performance measurement system to help in collecting and analysing relevant management information from an early stage should be the answer.

2.5.6 Logistics Support Management System Development

The core product of ILS and CALS is LSA (Logistics Support Analysis). LSA is an iterative analytical process which is employed throughout the early phases of system development and often includes maintenance analysis, reliability-centred maintenance requirements, level-of-repair analysis, life-cycle cost analysis, and logistics modeling. The output of LSA is a well-structured logistics support plan which identifies spare/repair part types and quantities, test and support equipment requirements, maintenance tasks and levels, personnel quantities and skill-level training requirements, technical data and handling requirements, and facilities requirements. This output is also identified as LSAR (Logistics Support Analysis Record) and it constitutes the database of the input to a CALS application. A typical LSA generating process and data flowchart is shown in Figure 2.9.

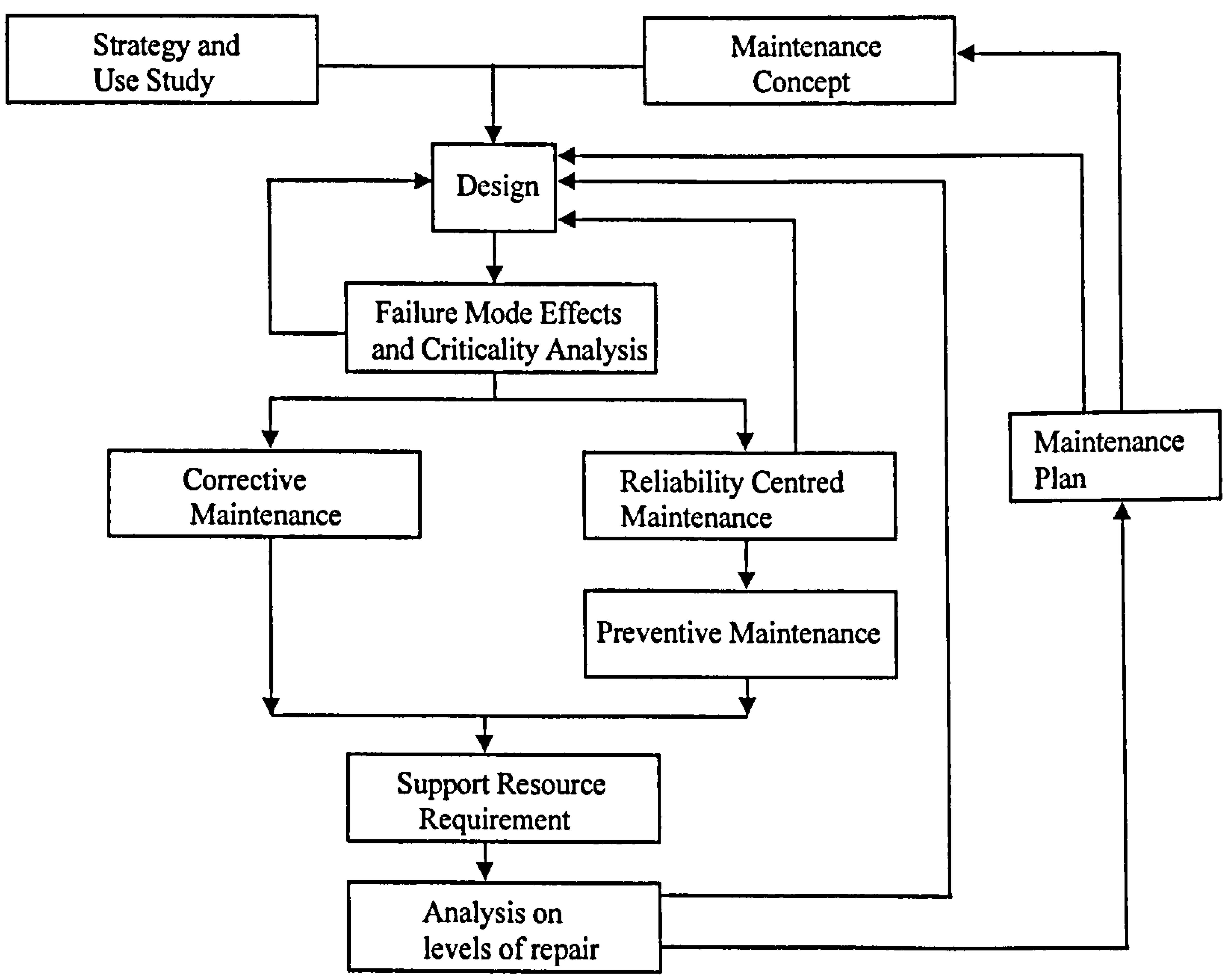


Figure 2.9 Data flow of LSA process in ILS

(Source : Galloway, 1997)

As an equipment design solution matures, the LSA directly sustains the activities to plan and provide the necessary logistic support. LSA provides the ground rules for initial and in-service provisioning which also defines maintenance requirements and determines support and training facilities.

In implementing ILS/CALS, many factors are developed to monitor and control the performance of existing system/equipment. These suggested factors are based on the monitoring of the quality, availability, reliability, maintainability, and cost of the applied facilities. These factors will be discussed to establish a Performance Measurement System (PMS) in the following chapters.

In general, the strategy and elements constituting ILS and CALS can be applied to the development of PFM; in particular those control factors constitute the generic indicators to monitor the operational performance of any facilities in PFM.

2.6 Performance Measurement System (PMS) Development and Benchmark Techniques

A Performance Measurement System (PMS) is a management tool composed of a set of performance measures to assist the assessment of how well the activities within a process or the outputs of a process achieve a specific goal (Hronec, 1993). In PFM, it is imperative to measure the performance of manufacturing facilities in order to monitor how the strategies are delivering the expected competitive advantage. If it cannot be measured there is no method of determining if an improvement has taken place. In implementation, PMS consist of two key elements, the identification of Performance Measures (PM)/ Performance Indicators (PI) and the benchmarking process. PM/PI are qualitative or quantitative variables which are decided throughout the manufacturing strategy formulating process. Benchmarking is the implementation of comparing the strategic requirements with pragmatic implemented results.

Benchmarking is "*the search for the best practices that will lead to extreme performance through the implementation of these practices*" (Camp, 1989). Also, benchmarking can be used as a goal-setting process, an aid in setting performance objectives to achieve performance improvements (Venetucci, 1992). The benchmarking process involves the systematic analysis and continuous efforts to compare the performance of an organisation against the performance of the leaders in that field. With the comparison between the company and world class manufacturing companies or world-wide industrial standards, the strategy to win the business and implementation policies can be decided sequentially. The key to successful benchmarking always depends on what is to be benchmarked, and with whom it will be benchmarked. The decision on what to benchmark must be made with reference to what impact is made upon customer satisfaction and what functions are key to the business strategy (Zairi, 1996).

2.6.1 The Role of PMS

Whether the PFM implementation will succeed or not depends a lot upon the development of an effective and efficient performance measurement system. Performance measures link the mission, strategy, goals, and processes of the organisation (Hronec, 1993).

The Performance Measurement System (PMS) is a monitoring tool which provides the linkage of the interface to translate the strategic requirement into the facilities management requirement. Properly utilised, performance indicators should highlight opportunities for improvement within companies today (Wireman, 1998). From reviewed literature, the most popular variables used as the PM are always mentioned and discussed with WCM, typical ones being Quality, Delivery Lead Time, Delivery Reliability, Design Flexibility, Volume Flexibility, and Cost (Dixon 1990, Maskell 1991, and Slack, 1998). The PM/PI establishment and benchmarking the performance with them reward essential information for the PFM decision-making in the end.

2.6.2 The Why, What, Where and How of Performance Measurement

In implementing PMS, workers and managers should work together to get the benefit of a proper performance measurement because of the operation gap it can reflect and improve. A PMS in PFM is an integration of all of the resources in the organisation and it is required due to the following reasons.

- ***A company cannot manage what a company cannot measure*** - Performance measures are the media of management because without them no target can be made.

- ***To determine what to pay attention to and improve*** - Resources in any organisation are limited and scarce. Performance measures provide the company the opportunity to make the right allocation of resources and to set the right priorities for improvement.

- ***Performance measures provide a "scorecard" for people to monitor their own performance levels*** - People like to know how well they are doing and where they should next focus for improvement.

- ***Performance measures show the standard for establishing comparisons*** - Quality is an aggregate name for a journey without a destination. If organisations want to be competitive, they must first set high internal standards which reflect their strength to enable them to carry out comparisons with their key competitors and to be the best in their class.

- ***Performance measures must comply with the strategic objectives*** - Effective strategy deployment can only be achieved if there are proper measurement systems in place. The company needs to measure all the time to ensure that their goals are being achieved.

In the current business climate, to be competitive, a company requires measures that can accurately reflect the company's performance in the future. These measures allow the organisation to focus on priority items and not waste resources on non-value added initiatives or programmes (Wireman, 1998).

2.6.3 The Evolution of PMS

Traditionally, the majority of performance measures of manufacturing business organisations are usually based on the cost and management accounting aspects which still remain largely unchanged (Maskell, 1991). These efforts place an emphasis on cost, price, and profit. On the other hand, the manufacturing management technology and processes have had numerous changes and these cannot be shown from these aspects.

Kaplan (1990), Dixon *et al* (1990), and Maskell (1991) analysed why the traditional measures are not suited to the current situation:

- The measures produced irrelevant or misleading information, or worse, provoked behavior that undermined the achievement of strategic objectives.
- Measures that tracked each dimension of performance in isolation were distorting management's understanding of how effectively the organisation as a whole was implementing the company's strategy.
- Traditional performance measures did not take into account the requirements and perspective of customers, both internal and external.
- Bottom-line financial measures came too late (monthly) for mid-course corrections and actions
- Cost-based measures are inconsistent with the new emphasis on quality, just-in-time, and using manufacturing as a competitive weapon.
- Traditional management accounting is no longer relevant or useful to a company moving toward a world class manufacturing environment.
- Customers are requiring higher standards of quality, performance and flexibility.
- Management techniques used in production plants are changing significantly.

Ghalayini, *et al* (1997) presented a comparison between traditional and non-traditional performance measures as shown in Table 2.5. The comparison table not only presents the changing of performance measures requirements but also provides a new direction for the design of a new PMS.

Table 2.3. Comparison Table of Traditional and Non-traditional Performance Measures *(Source: Ghalayini, Nobble, and Crowe, 1997)*

Characteristic	Traditional Performance Measures	Non-traditional performance measures
Basis of system	Accounting standards	Company strategy
Types of measure	Financial	Operational and financial
Audience	Middle and top management	All employees
Frequency	Lagging (weekly or monthly)	Real-time (hourly or daily)
Linkage with "reality"	Indirect, misleading	Simple, accurate, direct
Shop floor relevance	Ignored	Used
Format	Fixed	Flexible / variable
Effect on continuous improvement	Impedes	Support
Local-Global relevance	Static, non-varying	Dynamic, situation structure dependant
Stability	Static, non-changing	Dynamic, situation timing dependant
Purpose	Monitoring	Improvement
Support for new improvement approaches (JIT, TQM, CIM, FMS, etc.)	Hard to adapt	Applicable
Effect on continuous improvement	Impedes	Support

2.6.4 The New Performance Measurement Requirement for Manufacturing Business

In more recent years, manufacturing requirements have reflected the changes in market expectation and competition away from price alone to others such as quality, delivery lead time, flexibility, etc. To respond to these customer demands, and to increase competitiveness, various new technologies and management techniques have been introduced, even to small businesses, transforming the methods of managing and producing their products being very important to this survival. New performance measurement concepts have emerged which are directly related to successful manufacturing strategies (Salleh 1995).

Dixon and Vollmann (1990) discussed the requirements for new performance measurement as well. Their suggestions are:

1) Measurement approaches must support ever-increasing excellence:

- All employees should be involved in the drive to implement new ideas more quickly; the objective is total and continual organisational learning.
- Managers need to spend more time taking actions and less time reporting actions.
- Improvement actions must be integrated across functions and across company borders.

2) Managing effectiveness is achieved by integrating strategies, actions, and measures

- Evolution and learning can and must occur on all three dimensions. As strategic objectives are achieved, new ones are formulated; new actions are required to achieve the objectives, and new measures are needed to encourage and monitor those strategic actions. Moreover, obsolete measures must be discarded.
- The driving force for improvement often comes from strategies, but it can and should also come from actions and from measures. That is, new measures can lead to both an evolution in actions and a change in strategy.

Meyer (1994) also reported that *"The design of any performance measurement system should reflect the basic operating assumption of the organisation it supports. Ideally, a measurement system designed to support a team-based organisation should help teams overcome two major obstacles to their effectiveness: getting functions to provide expertise to teams when they need it and getting people from different functions on a team to speak a common language."* However, traditional measurement systems do not solve those problems. In creating process performance measures, Meyer (1994) suggested four steps:

(1) Defining what kinds of factors, such as time, cost, quality and product performance, are critical to satisfying customers

(2) Mapping the cross-functional process used to deliver results

(3) Identifying the critical tasks and capabilities required to complete the process successfully

(4) Designing measures that track those tasks and capabilities.

To measure the operational performance for world-class competition, what companies need is a process by which they can continually realign their strategies, actions, and measures, not just a new cost accounting system (Dixon and Vollmann 1990). Competitive environments vary widely between industries, within industries, and even within companies. Although what is considered to be valuable will differ in detail and the scope is based on the actual products and services wanted, today's customer demands on products are Quality, Price, Delivery, Products and Service. Maskell (1990) and Kaplan (1991) studied the transformation of traditional financially-based measures into the operation related measures and suggested the basic requirements are Quality, Delivery Lead Time, Delivery Reliability, Design Flexibility, Volume Flexibility, as well as Cost/Price.

The nature of manufacturing business today implies the use of different technologies at different manufacturing plants. Therefore, an integrated system must aggregate and present data from different shop floor control modules. Performance measurements and systems also differ from plant to plant, depending on the focus, technology, and goals of each plant. Hence, performance measurements should not be applied across the board but should change as customer's requirements change. Effectiveness must be the goal (Christopher, 1992). Based on the aforementioned review, a new performance system should include at least some of the following characteristics:

- ***They are directly related to the manufacturing strategy.***
- ***They primarily use non-financial measures.***
- ***They may vary between locations.***
- ***They change over time as needs change.***
- ***They are simple and easy to use.***
- ***They provide fast feedback to operators and managers.***
- ***They are intended to foster improvement rather than just monitor.***

2.6.5 Hierarchy of Performance Measures

According to the reviewed literature, many strategic measures and performance indicators are taken into consideration in the development of a PMS. Figure 2.10 depicts a summary of the structure of a PMS which contains typical but not exhaustive parameters related to the strategic objectives to monitor the performance of production facilities (Liu, *et al,* 1999). Different companies may develop their own parameters to fit their strategic objectives.

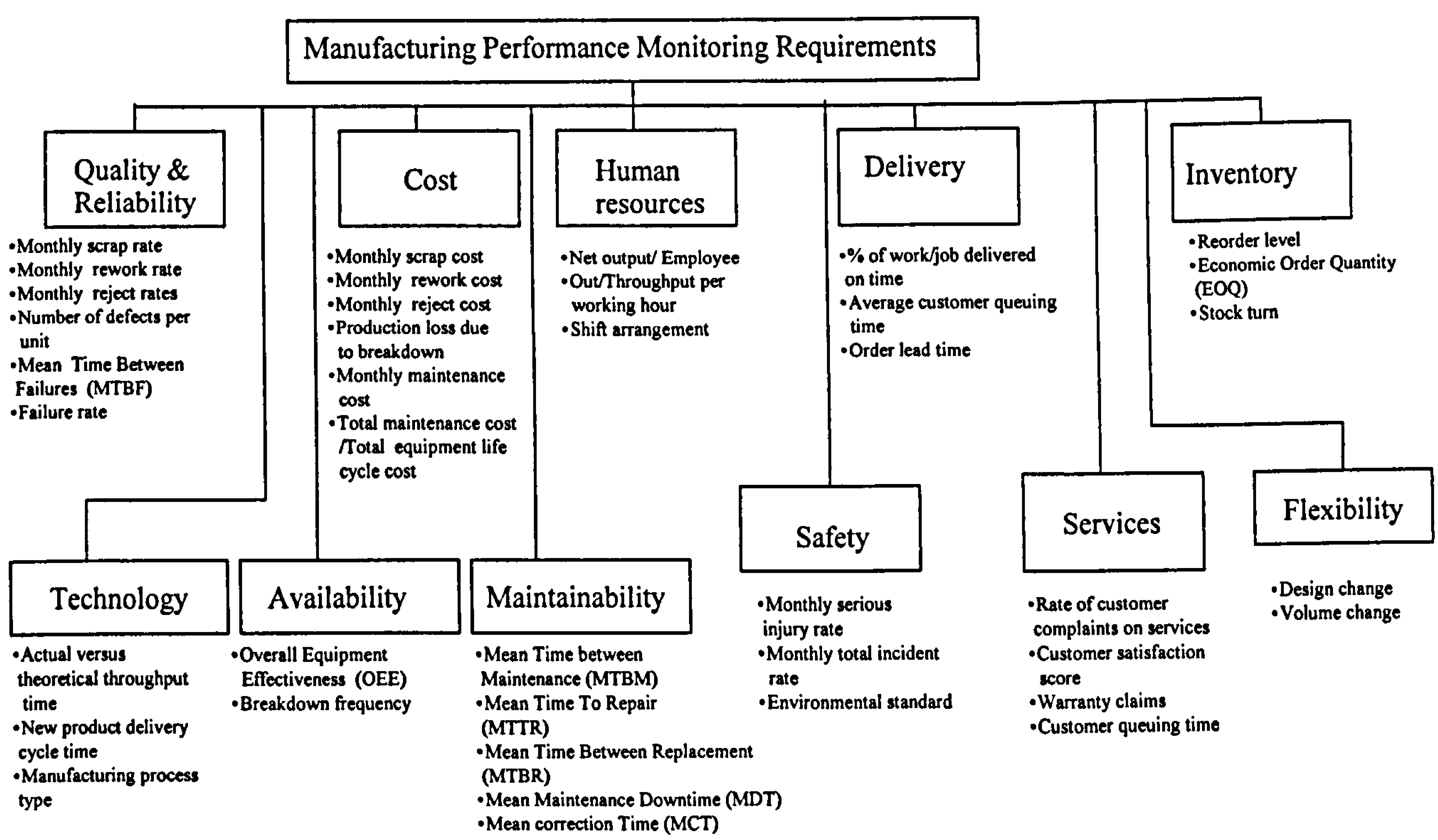


Figure 2.10 Performance Measures for Manufacturing System

2.6.6 Basic Benchmark Process

There are two types of benchmarking: product benchmarking and process benchmarking. (Partovi, 1994) Product benchmarking involves the process of reverse engineering whereby a firm acquires a superior product from another firm and breaks it down into its various components. Process benchmarking is an external, directed focus on an internal activity or operation in order to achieve continuous improvement (Partovi, 1994). The application of benchmarking in PFM is close to process benchmarking, i.e. to select proper measures to be monitored and to analyse the gap between the practical performance with the strategic requirement. The aim of benchmarking in PFM is to find a better solution for facilities management.

While there are two types of benchmarking, there are four ways of identifying process benchmarking partners (Pettersen, 1995):

1. ***Benchmarking internal operations*** – To find the best-performing unit within own company.

2. ***Benchmarking the competitors*** – This is rather difficult, because the competitor will not expose key information, however, the company can collect them from marketing information for reference.

3. ***Best-in-class benchmarking*** – Learning how to improve certain activities by benchmarking processes of companies, i.e. to analyse the competitors the best they can with their own company.

4. ***Strategic benchmarking*** – Identifying how a company should position its product in relation to its competitors, as well as suggesting what needs to be done to the processes or functions to support those competitive advantages. It is started with two additional stages: situation analysis, and product feature analysis.

By identifying how superior companies organise their processes, a company can seek to adopt and adapt their practices. Benchmarking can be an effective tool for planning and implementing change processes that lead to organisational improvement when the knowledge gained is converted into a detailed action plan to improve the competitive advantage (Pryor and Katz, 1993). Benchmarking is used as a goal-setting process, an aid in setting performance objectives to achieve performance improvements (Voss *et al* , 1997; and Venetucci, 1992) and this is the reason why benchmarking will be one of the main subjects to be discussed in PFM. Companies who over-estimate their competitiveness may become complacent, and thus delay adopting improvement programs and be overtaken by competitors whilst companies who are realistic will increase their chances of identifying the improvement areas which can have the most competitive leverage, and thus be able to compete on a more level playing-field (Voss, *et al*, 1997).

2.6.7 Current Benchmark Frameworks and Techniques

Pioneered by Xerox, benchmarking has been widely adopted by companies as an improvement initiative (Port and Smith, 1992). In an attempt to identify those areas where competiters had gained an advantage over themselves, Rank Xerox set out a ten steps benchmarking process (Camp, 1989), department by department, to compare their performance against their competitors. This comparative analysis extended from a comparison of technical features of equipment and cost data, through to a detailed examination of customer perceptions of quality and service.

Some other models may be applied such as the Spendolini five-step process (Spendolini, 1992). In discussing the benchmarking failure, experienced benchmarkers most often blame poor selection of the process to benchmark (Camp, 1989; and Spendolini, 1992). Partovi (1994) also stated that "Determining which function to benchmark is the crucial stage in the beginning of benchmarking" and he proposed a "two stages and seven steps" benchmarking model. Some of the current benchmark practices are introduced below.

2.6.8 Balanced Scorecard Technique

The complexity of managing an organization today requires that managers be able to view performance in several areas simultaneously. The aim of a balanced scorecard is translating vision and strategy from four perspectives which allows managers to look at the business performance comprehensively (Kaplan, 1992). They are:

- *Having a customer perspective - How do customers see us?* All businesses exist to satisfy customer requirements. In order to compete successfully, there is a need to start with the customer first. In addition, measurement has to be externally focused using external data such as service, quality, and cost.

- *Having an internal and business perspective - What must we excel at?* Building capability internally is essential to becoming competitive.

- *Having an innovation and learning perspective - Can we continue to improve and create value?* Modern competitiveness is based on fulfilling customer requirements through creativity and innovation. The consideration of people as the main asset is crucial and measurement of employee satisfaction and employee attitude is crucial. The challenge is to compete on a set of competencies which are capable of delivering future strategies.

- *Having a financial perspective - How can we look to shareholders?* Shareholders are another set of stakeholders and value added to shareholders has to be continuously monitored and measured.

The process of formulating the balanced scorecard is shown as Figure 2.11.

capability of the organisation and hence the agenda for developing new strategies (Johnson & Scholes, 1993). The aim of a SWOT analysis is to identify the extent to which the current strategy of an organisation and its more specific strengths and weaknesses are relevant to, and capable of dealing with, the changes taking place in the business environment. Although what follows is somewhat crude as an analytical device, it has proved in practical applications to be a helpful means of achieving these aims. The procedure can be undertaken in typical steps as follows:

1. *Identifying the current strategy or strategies that the company is following.* This should be the realised strategy of the organisation. This might be problematic due to management maybe not doing what the current strategy recommends but this assessment should be based on the true situation. The debate between the real situation and specific requirements is very important.

2. *Identifying the key changes in the company's environment.* While there is no fixed number which should be agreed upon, it is helpful to control the items on the list not to exceed seven or eight points (Johnson & Scholes, 1993).

3. *Identifying the key capability (strengths) and key limitation (weaknesses) of the company.*

The SWOT analysis is a simple generic analytical tool that examines the following aspects of the organisation and manufacturing function (Hull, 1998):

1) *Strength:* activities, systems, technologies, procedures, etc, which the manufacturing function performs well.

2) *Weaknesses:* activities, systems, technologies, procedures, etc. which the manufacturing function does not perform to an accepted standard.

3) *Opportunities:* activities, systems, technologies, procedures, events, potential events, etc., which the manufacturing function could exploit.

4) *Threats:* activities, systems, technologies, procedures, events, potential events, etc., which may prevent the manufacturing function achieving its aims.

The application of SWOT analysis in PFM provides a basis for the improvement of the current situation. An illustration example will be introduced in Chapter 3.

A SWOT analysis provides a mechanism for systematically thinking through the extent to which the organisation can cope with its environment. The key point is that the analysis requires an understanding of both the environment and the resource capabilities of the company.

2.6.10 Gap Analysis and Polar Diagram Application

The Gap Analysis is one of the typical benchmark techniques and it becomes clearer with the combination of Polar Diagram application. A typical Polar Diagram is shown in Figure 2. 12.

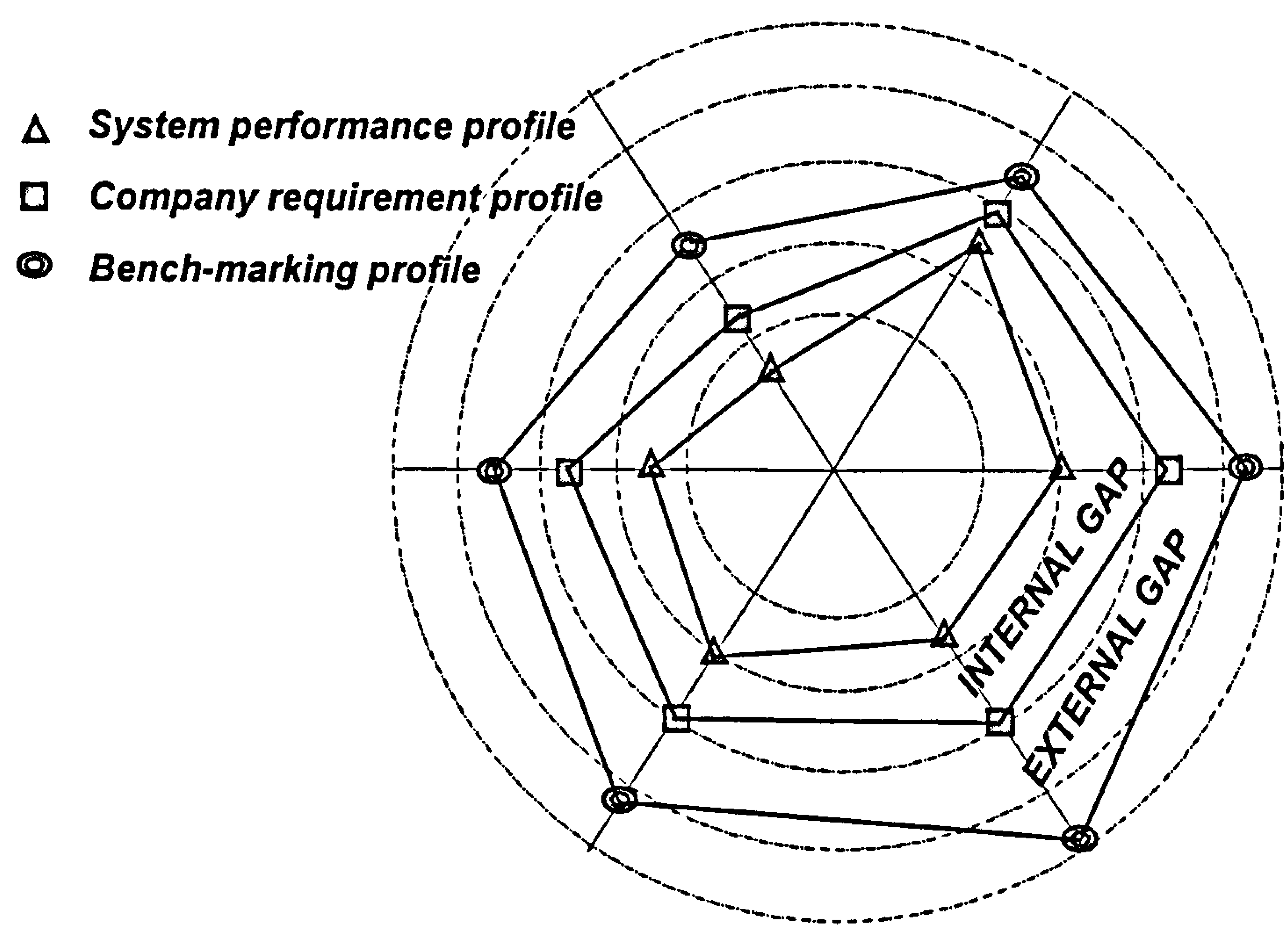


Figure 2.12 The Example Polar Diagram for Gap Analysis

The two types of benchmarking processes that Gap Analysis can be applied to are:

- *Internal benchmarking:* This compares the performance of an organisation's internal activities (system's performance profile) and processes with the strategic objective (company requirement profile) to establish standards within the organisation.

- *External benchmarking (Competitive benchmarking):* This involves the investigation of competitors (benchmarking profile), with the aim of identifying a company's current position (company requirement profile) compared to market or industry standards. The purpose of carrying out such a practice is to enable a company to compare their performance with the performance of competitors' in the same field.

The most important benefit of Gap Analysis is that it allows a company to see beyond its existing performance. As the company benchmarks other organisations, it will greatly improve the ability of seeing the solutions of the future to fit the problems of the present.

Gap Analysis combined with the application of Polar Diagram gives a clear deviation for the company to improve. The advantages of Polar Diagram for the representation of the result of gap analysis have been proposed by many authors including Slack *et al* (1998) and Hull (1998).

2.6.11 Current Self-Assessment Benchmark Models

Total Quality Management (TQM) seeks to foster a climate of co-operation, team work and organisational objectives. From a strategic viewpoint, PFM supports the implementation of strategic objectives, therefore the criteria for quality improvement can be taken into consideration in developing the PFM benchmark requirements. Several national and regional benchmark models are developed on the initiatives of TQM. The more popular ones are The Deming Application Prize, Malcolm Baldrige National Quality Award, and European Quality Award (EQA). The following Table 2.4 illustrates the summarised comparison in terms of the self-assessment criteria.

Table 2.4 The Deming, Baldrige, and EQA Criteria Comparison Table

(Source: Nakhai, 1994)

	Deming Prize	Baldrige Award	European Quality Award
Orientation	Established in 1951 in Japan	Established in 1987 by US congress in U.S.A	Established by EFQM (European Foundation for Quality Management) in 1991
Key self-assessment criteria	1. Company policy and planning 2. Organisation and its management 3. Quality control education and dissemination 4. Collection, transmission, and utilisation of information on quality 5. Analysis 6. Standardisation 7. Control 8. Quality assurance 9. Effects 10. Future plans	1. Leadership 2. Information and analysis 3. Strategic quality planning 4. Human resource development and management 5. Management of process quality 6. Quality and operational results 7. Customer focus and satisfaction	1. Leadership 2. Policy and strategy 3. People management 4. Resources 5. Processes 6. Customer satisfaction 7. People satisfaction 8. Impact on society 9. Business results

The processes of these models are illustrated in Appendix A. These models do not provide enough details for an implementation plan but they provide the necessary guidelines for a self-assessment framework. From these benchmark criteria comparisons, some generic requirements can be adopted and applied for the implementation principles on PFM development due to the result that PFM will impact the performance of quality in the end. These guidelines are:

- Company strategy and policy are established towards customer satisfaction
- Human resources and processes planning and control are necessary for operational quality

- Information collection, transmission, analysis and utilisation guarantee the quality assurance of the business results

2.7 Decision-Making Support Analysis Techniques

The decision-making process in PFM is complicated because it involves qualitative and quantitative measures and historic data. This section studies some current practices in decision-making support analysis techniques. A detailed description of each practice is included in Appendix B.

2.7.1 Utility Value (UV) Calculation

Utility Value is used as an analysis tool to assist the calculation of the relative weight of importance in multiple criteria of each criterion and gain an integrated value with respect to each other. The system utility can be considered to be a function of the product group importance, the importance of the competitive criteria for the individual product group and the performance of the individual product with respect to the competitive criteria (Hull, 1998). The Utility Value of a system is shown as:

$$U = Fn(I(\pi), N(\chi,\pi), \theta(\chi,\pi))$$

Where:

$I = Relative\ importance\ derived\ from\ manufacturing\ background$

$N = Market\ requirements$

$\theta = Manufacturing\ performance$

$\pi = Product\ group$

$\chi = Manufacturing\ competitive\ criterion$

The UV application in PFM is to get the profile of the overall performance of each existing machine (group) with respect to each corporate competitive criterion. The overall performance of each machine (group) can be turned up in each criterion such as quality, delivery reliability, delivery lead time, design flexibility, volume flexibility, and Cost. The performance of each criterion can be divided into subordinate performance measures and indicators. The choice of the performance measures and indicators is decided by the organised PFM team. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirement. This result also provides an assessment for the second stage's requirement of the improvement plan. A more detailed description of the application is illustrated in Appendix B.1.

2.7.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a decision-making aid tool for dealing with complex, unstructured and multiple attribute decisions. It was developed during the 1970s by Prof. Thomas L. Saaty (Partovi, 1994). There are three basic steps in using AHP:

1. ***Step 1: The description of a complex decision problem as a hierarchy – distinguishing the unstructured decision into components and then arranging them in a hierarchical order.***

   In a typical hierarchy, the top level reflects the overall objective of the decision problem. This formulation process is very strategy-oriented. The elements affecting the decision are called criteria and are represented at the intermediate levels. Criteria can be subjective or objective depending on the means of evaluating the contribution of the elements below them in the hierarchy. Criteria are mutually exclusive and their priority or importance does not depend on the elements below them in the hierarchy. The lowest level comprises the decision options or alternatives. The number of criteria or alternatives should be reasonably small to allow consistent pair-wise comparisons. A hierarchy can be divided into several sub-hierarchies sharing only a common topmost element.

2. ***Step 2: The prioritisation procedure- determining the relative weight of importance of the elements in each level.*** Elements in each level are compared pair-wise with respect to their importance to an element in the next higher level, starting at the top of the hierarchy and working down. A number of square matrices called preference matrices are created in the process of comparing elements at a given level. The decision maker can express his preference between each two elements verbally as equally important, moderately more important, strongly more important, very

strongly important, or extreme strongly important. These descriptive preferences are then translated into numerical ratings such as 1, 3, 5, 7 and 9. The nominal scale used in AHP enables the decision makers to incorporate experience and knowledge in an intuitive and natural way.

3. ***Step 3: The calculation of results – deriving relative weight of importance for the various elements.*** The relative weight of the elements of each level with respect to an element in the next higher level are computed as the components of the normalised eigen vector associated with the largest eigen value of their comparison matrix. The composite weight of the decision alternatives are then determined by aggregating the weights throughout the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weight along each segment of the path. The outcome of this aggregation is a normalised vector of the overall weight of the options.

In practice, AHP has been used to model and analyse production decisions, one of them being maintenance decision making (Labib, 1998). It can be made much easier using personal computer software, such as Export Choice. This software is very user-friendly and can greatly facilitate the user of AHP in the workplace. An example of the application of AHP in PFM is shown in Appendix B.2.

2.7.3 Weibull Analysis

Weibull analysis is a technique used to assess the reliability of failure data. The items to be monitored and applied are reliability, hazard rate and the failure distributions (Logothetis, 1992).

Reliability is a measure of the ability of a product to function successfully, when required, for the period required, under specified operating conditions. It is usually expressed as a mathematical probability, and so can lie between 0 or 0% (completely unreliable) and 1 or 100% (perfectly reliable). The failure percentage is (100-R) where 'R" is the percentage reliability.

If we consider failures in a population of items, the time to failure will have some distribution. We can then quantify the reliability of failure percentage at any desired age by estimating this failure distribution using data from a sample.

The failure distribution is characterised by a measure called the hazard rate, defined by:

$$HR = Rate\ at\ which\ remaining\ items\ fail$$
$$= \frac{Number\ of\ units\ failing\ in\ a\ time\ interval}{(Number\ of\ survivors\ at\ start\ of\ interval)\ x\ (Length\ of\ time\ interval)}$$

There are three types of hazard rate (Logothetis, 1992):

1. *Decreasing - infant morality*: early failures resulting from construction errors.

2. *Constant – useful life / prime life*: random failures resulting from misuse by customer, occasional operating stress exceeding designed strength, etc.

3. *Increasing – wearout failures* due to wear, fatigue, chemical aging such as corrosion, etc.

The application of Weibull Analysis is introduced in Appendix B.3.

2.7.4 Quality Function Deployment (QFD)

QFD was first proposed and used in 1972 by Mitsubishi Heavy Industry's Kobe Shipyards site. Toyota and its suppliers then developed it in numerous ways. It is a kind of conceptual map that provides the means for inter-functional planning and communication. Its important characteristics are its (Hauser & Clausing, 1988):

1. Focus on customer requirements.

2. Use of multidisciplinary teamwork.

3. Dynamic conceptual map called the "House of Quality" used to document information and decisions, and aid communication.

The majority of the literature relating to the use of QFD focuses on further developments of the technique for its initial application in product design. It brings together the essential elements and characteristics of the various phases in the life cycle of a product.

Implementing the QFD into PFM, it is used as a tool to help the recognition of the interrelationships between the engineering properties of the product and the customer's requirement, so that the customer's needs are anticipated, prioritised and effectively incorporated into the product. Also, the same technique can be manipulated into the description of the interrelationships between the facilities performance monitoring and the corporate strategic requirements because the customer's requirements are compatible with the strategic objectives.

The basic procedure to follow is the construction of the house of quality.

1. *Step 1: Identifying customer requirements and major concerns related.*
2. *Step 2: Evaluation of the performance of own company and competitors.*
3. *Step 3: The facilities are then described in terms of their Performance Characteristic.*
4. *Step 4: The main body of the house of quality is now filled in the historic data.*

A detailed application and implementation example of QFD on PFM framework is described in Appendix B.4.

On the whole, QFD is very effective for determining opportunities of improvement to satisfy customer requirements. The house of quality is a summary of data that can serve as a permanent and complete record of all of the relevant information, and provide a solid and valuable initiative for further improvement (Logothetis, 1992).

2.8 Conclusion

Since Skinner (1969) pointed out the missing link between the manufacturing functions and strategy within American firms, manufacturing strategy or what is also called operational strategy has grown rapidly. However, the use of manufacturing in corporate strategy as a management practice is not widespread (Skinner, 1969, 1974, 1996). From the literature review, the process of manufacturing strategy formulation to capture the strategic requirements is a vital factor to manufacturer. Throughout the reviewed literature, facilities management is one of the important concerns in manufacturing strategy formulation but rarely found is the research of the linkage between them. Only

Hayes and Wheelwright (1984) proposed that the decision process of capacity and facilities should be strategy driven and the product life cycle is related indirectly to the firm's manufacturing strategy. However, the implementation process of such a linkage was not found from the literature. There is still a lack of systematic research for the implementation process of production facilities which should follow the creation of the strategic requirements. There is a need for something to fill this gap and Production Facilities Management (PFM) may be the answer.

The concepts of Total Productive Maintenance (TPM), Terotechnology, Reliability-Centred Maintenance (RCM), Asset maintenance management, Integrated Logistics Support (ILS), and Life Cycle Cost/Profit (LCC/LCP) focus on various topics in PFM. The following table illustrates the strengths and weaknesses of the reviewed knowledge and current practices.

Table 2.5 Current Management Practices and Knowledge Strengths and Weaknesses Analysis Table

Current practices and knowledge	Strengths	Weakness	Improvement area
Manufacturing strategy formulation • Skinner (1969, 1974, 1996) • Hayes and Wheelwright (1984) • Platts and Gregory (1988, 1990) • Stonebraker (1994) • Wild (1995)	• Manufacturing strategy formulation process and steps • Well-structured manufacturing aims, initiatives, objectives, and goals identification process • Top down systematic strategy establishment	• Much focused on strategy formulation, and lack of detailed methodology to transform strategic concerns into practical implementation plan in operation • Lack of bottom-up operational support	• Integration with operational performance monitoring system development

Current practices and knowledge	Strengths	Weakness	Improvement area
TPM (Total Productive Maintenance) • Nakajiima (1971, 1988) • Gotoh (1991) • Sekine and Arai, (1998)	• People-oriented approach to maintenance • Covers all departments • Performance measurement system establishment • Planned maintenance procedures • Data collection • Fault finding • Continuous improvement • Measurable improvement • Sufficient research & documentation	• Focused on the performance of the equipment • Lack of integration with the strategic concerns	• Integrating maintenance plan with manufacturing strategy • Strategically driven PMS development
RCM (Reliability Centred Maintenance) • Smith (1993) • Moubray (1997) • Knezevic (1997)	• Safety and technology driven • Traceability of the documented data • Facilities reliability improvement • Continuous operational performance monitoring • Facilities quality improvement	• Focused on the needs of asset, not the shape of the organisation • Lack of integration with the strategy	• Strategically driven PMS development • Facilities life cycle performance monitoring
BCM (Business Centred Maintenance) • Kelly (1998) • Labib (1996) • Campbell (1995)	• Integration of maintenance and business strategy • Strategically driven maintenance plan guideline • With measures of reliability of components and plant	• Lack of implementation plan	• Strategically driven PMS development • Facilities life cycle performance monitoring

Current practices and knowledge	Strengths	Weakness	Improvement area
WCM (World Class Manufacturing) • Maskell (1991) • Kaplan (1990) • Todd (1995) • Vollman (1990)	• Performance measures development • Performance benchmark	• Lack of strategy integration and detail implementation plan	• PMS development and implementation • PMS and manufacturing strategy integration
CMMS (Computerised Maintenance Management System) • Wireman (1998)	• Rational database establishment • Facilities performance measures	• Lack of integration with manufacturing strategy • Lack of focus	• PMS development and implementation • PMS and manufacturing strategy integration
Life Cycle Management, ILS (Integrated Logistics Support) & CALS (Computerised Logistics Support) • US DoD (1983) • Blanchard (1992) • UK MoD (199 • Froome(1997) • Gallaway (1997) • Wu (1999)	• Optimising LCC (Life Cycle Cost) • Structured logistics support plan for facilities • LCC (Life Cycle Cost) planning and control • Operational performance measures development and monitoring • Systematic life cycle approach	• Lack of integration with strategy • Lack of national and international standardisation	• Strategically driven PFM design • PMS development and implementation • PMS and manufacturing strategy integration

The TPM concept has succeeded very well in making maintenance into an overall company-wide issue, by focusing on continuous improvement, autonomous small group activities, training, education, communication and flow of information. The crucial factors are the participation of operators and the concept that TQM has to be applied first. TPM does not pay attention to any specific tool or technique for preventive maintenance (Nakajima, 1988). However, TPM not only addresses maintenance, but all aspects of the operation and installation of manufacturing facilities. It shows how all production operations should be linked to produce an overall result.

Terotechnology is a British concept focusing on the link between maintenance costs and feedback of proper information to designers and constructors, relying on maintenance optimisation and life cycle costing (Husband, 1976). Although it is true that TPM, terotechnology, and ILS/CALS have economic LCC as the common goal, they differ in terms of the precise target. TPM in Japan aims to maximise equipment effectiveness. In effect, it is the same as terotechnology's goal of attaining an economic life cycle cost. Logistics in the United States is an old military term referring to support for the front line through the procurement, storage, transportation, and maintenance of manufactured goods and systems. The updated methods of logistics are an integration of the concepts of LCC, reliability engineering, and maintenance engineering which is an aforementioned concept of ILS. However, the initiatives of Terotechnology are creative. Today, because the advanced IS/IT can support real-time data access ability, the BCM enhances the integration of maintenance management with strategic objectives, the ILS and CALS formulates the structure of product life cycle management and LCC reduction is one of the key elements in management. All of these latest developments let Terotechnology become a possible mission.

RCM is a systematic approach that differs from TPM and Terotechnology. RCM features a systematic road map for preventive maintenance in complex plants such as the airline industry. The fundamental principle of RCM is that scheduled maintenance has little effect on the overall reliability of a complex item, unless the item has a dominant wear out failure (Smith, 1993). RCM almost ignores cost. It does not recognise maintenance as fundamentally an economic problem, but tries to achieve the "inherent reliability" of the system. RCM also shows how critical a piece of equipment is, its failure mode and the most appropriate maintenance regime for it. Firms could benefit from combining the RCM method with the TPM philosophy to make a comprehensive maintenance plan and operational performance monitoring and control.

Asset management takes a company-wide life cycle approach to equipment but, unlike TPM, it focuses on economic and financial issues, and not engineering (Pintelon and

Gelders, 1992). Terotechnology, on the other hand, tries to combine both issues (Husband, 1976).

LCC/LCP focuses on external effectiveness and how maintenance can contribute to improve revenues (Ahlmann, 1984). ILS is the American counterpart to these life-cycle concepts, with a greater emphasis on logistics (Blanchard, 1992).

As discussed throughout the literature review, there are some areas which could be improved:

- There is still a need for more attention on manufacturing strategy formulation. The activities of PFM should be organised to support the strategic objectives or strategically driven approach.

- PFM involves much indecision due to a range of decision-makers with conflicting perceptions and requirements. The critical issue of implementing PFM is lack of a systematic, step-by-step approach to link the corporate strategic requirements into the production facility management activities.

- The differences and borderlines between these background concepts are vague and vary between authors and users and each concept has its own focus, strengths and weaknesses. There is a need for the development of a framework to integrate the strengths of them to help to guarantee successful facilities management.

- Integration is the future. The missing link is a tool to translate the strategic objectives into the implementation of operational planning and control from the shop floor.

- There is a need for the development of a performance measurement system for the purpose of monitoring and decision making analysis.

- As the requirement of standardising the formal development and implementation process in PFM, it is recommended to develop an implementation workbook in practice.

Chapter 3
Research Approach and Methodology

3.1 Introduction

The literature review (see chapter 2) was used to identify the main problem of the research background. The issue identified from the reviewed literature is that there is a lack of a systematic, step-by-step approach to link corporate strategic requirements into Production Facilities Management (PFM) activities. This chapter establishes an aim for the research and proposes a programme to assist in the fulfillment of the aim. In order to establish an appropriate research programme, this chapter also discusses the process of choosing the strategy and research methodology for this research. The achievement of the design of the programme is based on the findings from the previous literature review in Chapter 2.

The research programme needs to consider the source and collection of relevant data, the specifications and development of a new method and its evaluation. Methods such as data collection, analysis and evaluation are considered and discussed in this chapter so as to find a suitable research methodology.

3.2 Development of Research Aim

Based on the literature review, it has been seen that the integration of the manufacturing strategy and production facilities management concepts could assist companies to enhance their manufacturing functions toward retaining the competitiveness of the business. Nevertheless, there are still some barriers prohibiting such integration. Although there is broad academic agreement on the context and content for a manufacturing strategy, the process that links these elements is not spread wide enough (Skinner, 1996). The maintenance goals and strategies of production facilities should be formulated to support the corporate strategy and business drivers (Jonsson, 1997). The process that links the facilities management and indecision in investment in them into manufacturing strategy still remain under-researched. To face the challenge of agile manufacturing (Cheng *et al*, 1998), there appears to be a need for research on the process of the integration of the manufacturing strategy with the management of production facilities. Hence, a valuable contribution could be made through an integrated activity mixed with the corporate strategy, asset management, operational performance monitoring, facilities maintenance/enhancement/replacement decision making. Therefore, the aim of the research is: "*To develop, test and refine a strategically driven PFM framework to support the manufacturing strategy and develop a step-by-step implementation process by exploring the academic theories and industrial practices*."

3.3 Research Methodology

Based on the above aim, a research programme is designed to direct the following investigation and development implementation in a sequence. This section describes each phase of the research programme and the rationale for the research concerns for each stage.

3.3.1 Choice of Research Strategy

Perry (1996) stated that "*There are two kinds of PhD research methodologies, they are qualitative research and quantitative research.*" Table 3.1 summarised the difference between these two aspects.

Table 3.1 Different Aspects of the Qualitative and Quantitative Research

(Source: Perry, 1996)

	Qualitative Research	*Quantitative Research*
Research problem	How? & Why?	Who (how many)? & What (how much)?
Literature Review	Exploratory – What are the variables involved? Research questions are developed	Explanatory – What are the relationships between the variables that have been previously identified and measured? Hypotheses are developed
Methodology	Case study research or action research	Survey or experiment

Table 3.1 illustrates the aspects in term of 'pure' exploratory and explanatory research. Nevertheless, in some PhD research, there may be a mix of qualitative research questions

and quantitative hypotheses, and a case study methodology can combine both in either exploratory or explanatory research (Yin, 1989). In identifying the research purpose, Robson (1993) stated that there are three kinds of classifications of the research purpose. Table 3.2 illustrates the matrix of the classification of the research purpose and the most suitable research aspect.

Table 3.2 Classification of Research Purpose and Research Approach Aspect Matrix Table ***(Source: Robson, 1993)***

Classification	Purposes of the Enquiry	Suitability of Research Approach
Exploratory	• Find out what is happening • Seek new insights • Ask questions • Assess new phenomena in a new light	Usually, but not necessarily, qualitative
Descriptive	• Portray profile of persons, events, or situation • Extensive previous knowledge requirement	May be qualitative or quantitative
Explanatory	• Seeks explanation of situation • Seeks explanation of problem	May be qualitative or quantitative

In choosing a research strategy, Robson (1993) also stated that there are three kinds of traditional research strategies. Table 3.3 illustrates the different features and their relationship with the purpose of the research.

***Table 3.3 Research Strategy and Research Purpose Classification Matrix Table** (Source: Robson, 1993)*

Research Strategy	Characteristics of strategy	Features of strategy	Suitability for the research purpose
Experiment	Measuring the effects of manipulating one variable on another variable	• Samples selection • Samples allocation • Measurement of variables • Hypothesis testing	Explanatory
Survey	Collection of information in standardised form from groups of people	• Samples selection • Relative data collection • Questionnaire employment • Structured interview	Descriptive
Case Study	Development of detailed, intensive knowledge about a single 'case', or of a small number of related 'cases'	• Single case selection • Case context study • Information & data collection • Observation • Interview • Documentary analysis	Exploratory

Table 3.3 has suggested the application matrix amongst them. However, this is not a necessary or immutable linkage. "*Each strategy can be used for any or all of the three purposes*"(Yin, 1981). For example, there can be explanatory, descriptive and exploratory case studies. Robson (1993) stated that "S*pecific methods of investigation need not be tied to particular research strategies.*" Both of them explore that it is flexible in choosing the strategies for implementing research in real world. The purpose of this research is not only concerned with contributing to knowledge but also desires to seek a potential usefulness in relation to practice in the real world. Therefore, the strategy and methods that are taken in this research is a mixture of them.

3.3.2 Key Elements to Establish a Research Programme

To establish a research programme, Morris *et al* (1987) suggested six sections to be considered. These are shown in Table 3.4 which also demonstrates the relationship between these sections with the methodology techniques adopted in the current research.

Table 3.4 An Annotated Cognitive Domain Taxonomy Table

(Source: Modified from Ince, 2000 which is adapted from Morris et al, 1987)

Section (Key Elements)	Significance	Implementation of the Present Research and Action Adapted
1. Knowledge	Recalling information pretty much as it was learned. Knowing the major areas and methods of enquiry	Data collection • Literature Review • Conference • Exhibition • Company interviews
2. Comprehension	Reporting information in a way other than how it was learned in order to show that it has been understood	Research analysis Qualitative and quantitative analysis
3. Application	Use of learned information to solve a problem	Research analysis Specification of the new method
4. Analysis	Taking learned information apart	Research analysis Specification of the new method
5. Synthesis	Creating something new and good based on some criteria	Research analysis Development of the new method
6. Evaluation	Judging the value of something for a particular purpose	Research evaluation

3.4 Data Collection

3.4.1 Selecting Samples

Sampling is an important aspect of life in general and research in particular (Robson, 1993).

Sampling is closely linked to the validity and generalisability of the findings in an enquiry. Validity is concerned with whether the findings are really about what they appear to be about. Generalisability refers to the extent to which the findings of the enquiry are more generally applicable (Robson, 1993). Validity and generalisability are the two fundamental issues of the findings of this research.

Ince (2000) adapted Black's statement in 1993 about the selection of criteria for evaluating representativeness. Black (1993) has created a list as follows: (1) ***Whole population***, where all findings apply to the whole population. (2) ***Random selection from a specified population***, while there is no guarantee that the sample is perfectly representative, it is the soundest approach giving the highest probability that a sample is representative. (3) ***Purposive sampling from a specified population***, where some attempt has been made to select a representative sample through specific criteria or characteristics related to variables that are to be controlled. (4)***Volunteers***, this will include a sample generated by accident, convenience etc. While there is some endeavour to obtain a sample that could be considered representative, such a sample is not very convincing. (5) ***Unidentified group***, where the description of the sample or sampling technique is not sufficiently clear either to indicate the population or to justify any generalisability.

The sampling technique used in this research is more likely to be options (2) and (3) which means to randomly select the respondents from manufacturing industry in particular from people in charge of the fabrication, maintenance and logistics operations.

3.4.2 Interview Surveys and Postal Surveys

Interviews and postal surveys are the most popular techniques for data collection, in particular, being used in a quantitative (explanatory) research strategy. Surveys can collect information about the distribution of a wide range of 'people characteristics' and of relationships between such characteristics.

The interview process is treated as a conversation initiated by the interviewer for the specific purpose of obtaining research objectives of systematic description, prediction or explanation (Cohen *et al*, 1989). The advantages and disadvantages of them are discussed and stated by Robson (1993) as shown in Table 3.5.

Table 3.5 Advantages and Disadvantages of Interview and Postal Survey Analysis Table (Source: Robson, 1993)

	Interview Survey	*Postal Survey*
Advantages	• Question clarification • Encouragement of participation and involvement	• Often the only and easiest way of retrieving information • Extremely efficient at providing large amount of data • Low cost • Short period of time
Disadvantages	• Data may be affected by interviewers' characteristics • Data may be affected by the interactions of the interviewer/respondents • Respondents may feel their answers are not anonymous and be less open	• Typically low response rate • Cannot detect the ambiguities in and misunderstandings of the survey questions • Cannot detect the honesty of the respondents

However, interviews work more effectively than postal surveys when recall and recognition questions are linked together (Ince, 2000).

In implementing a survey, the proper design of the questionnaire, the number of interviewees and the time factors involved are the most difficult variables to be specified. Powney et al (1987) stated that the questions asked must be developed in such a way that the answers are relevant to the research. Czaja et al (1995) also stated that "*The survey* *questionnaire is the conduit through which information flows and analysis; it is our link to the phenomena we wish to study.*" In order to optimise reliability, both interviews and postal surveys are executed in the current research. This study aims for an average time duration of two hours time duration for the interview and 40 minutes for the completion of the questionnaire.

3.5 Research Analysis

The research strategy needs to consider the collection and analysis of the relevant data. As there are two kinds of research methodologies, i.e. the quantitative research and qualitative research, there are two methods of dealing with the collected data. The decision to use quantitative analysis or qualitative analysis has a relationship with what the analyst is interested in and the tactic that he or she is supposed to employ. Miles and Huberman (1994) have identified various tactics that can be used to draw conclusions and test the validity of data. They are the tactics for generating meaning and for testing or confirming findings. In general, quantitative data analysis is much closer to the tactic for generating meaning from data and qualitative analysis is much closer to the tactic to use the data to test or confirm findings. In generating the tables for analysis, tables of statistical data are presented in quantitative research and matrices are used in qualitative research (Perry, 1996 adapted from Miles & Huberman, 1985).

3.6 Research Evaluation

Rutman (1977) stated that evaluation is the foremost process of applying scientific procedures to accumulate reliable and valid evidence on the manner and extent to which specified activities produce particular effects or outcomes. Systems should be developed and checked collectively with the people who are potential users and who are experts on the subjects (Gundogan, 1995). Otherwise, there would be huge isolated islands of very useful information within an organisation (Gundogan, 1995 derived from Ziarati, et al. 1995).

"The purpose of an evaluation is to assess the effects and effectiveness of something, typically some innovation or intervention: policy, practice or services. This can be done by using experimental, survey or case study research strategies – or some appropriate hybrid or combined strategy" (Robson, 1993). In this research, the evaluation involves a postal survey, internal test of the developed model and interviews with selected participants in charge of the fabrication, maintenance and logistics operations. The purpose of the evaluation is to ensure that the proposed model will have a considerable contribution to the academic knowledge of Production Facility Management and also provide relevant advantages to address the needs of manufacturing industry.

3.7 Overview of Research Methodology

Figure 3.1 gives an overview of the methods to be used for the present research. These include the research type, data collection and analysis, and evaluation method.

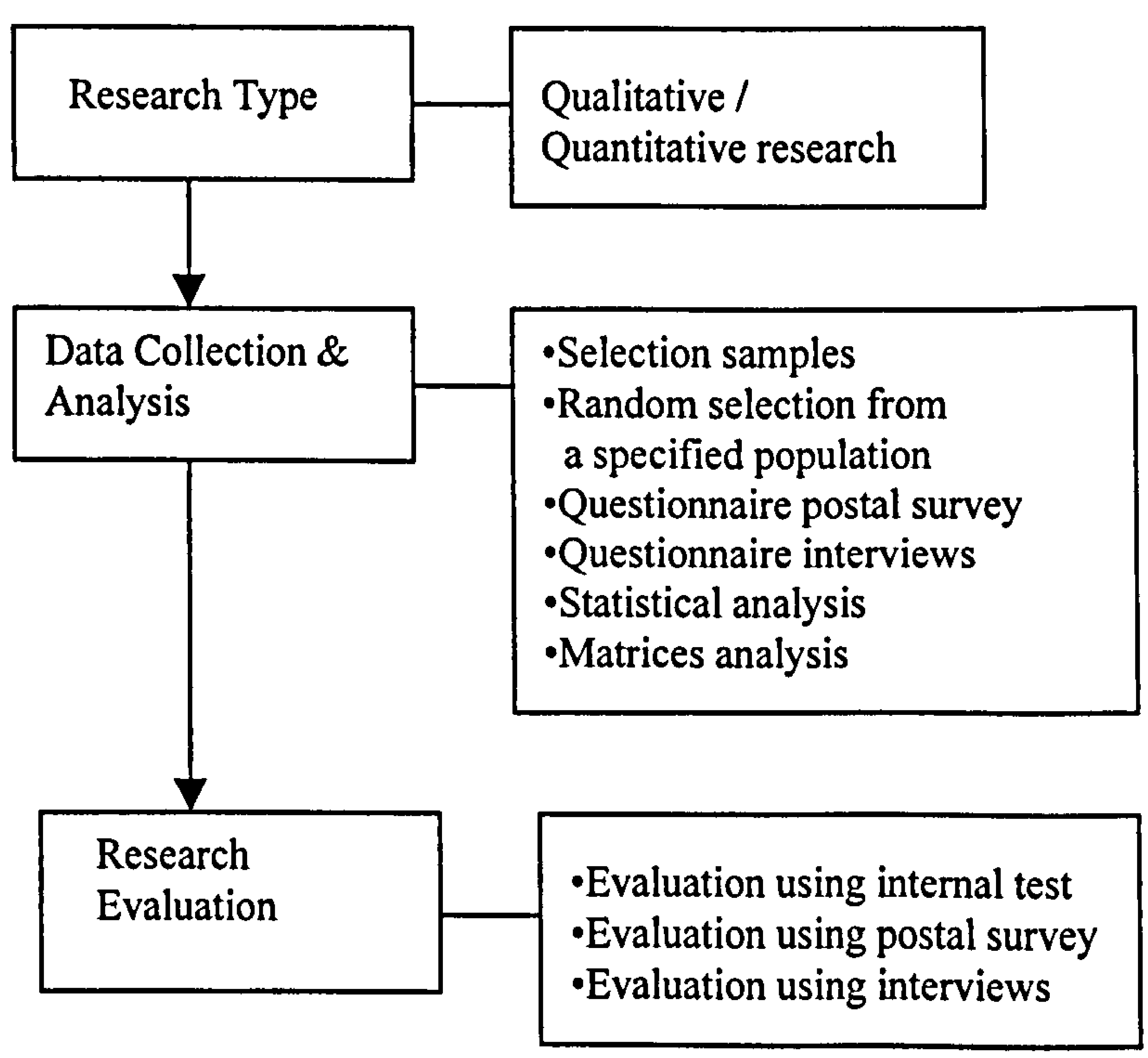


Figure 3.1 Overview of the Methods to be Used in the Research

3.8 Development of a PFM Implementation Workbook

Because of the need for consistency in the development and implementation process, it is recommended to standardise the whole process in an implementation workbook. As Greenhalgh (1991) stated, a structured and formatted implementation document would provide at least the following benefits.

1. It provides a practical way of thinking about strategy.
2. It stresses direction and focus.
3. It flows naturally from the analytical stage.
4. It leads easily into the operating plan.
5. It is an instrument of communication.

The utilisation of a step-by-step workbook to assist the implementation process can be found in the real world. Neely and Platts (1996) developed a step-by-step workbook to get the performance measures of the company. Hull (1998) also developed a step-by-step workbook to assist the implementation process to capture the strategic requirement in designing a manufacturing system. In order to assist the application of the developed PFM framework, a step-by-step implementation workbook is also developed in the research programme.

3. 9 Research Programme Design

In order to realise the aim of the research, a structured implementation programme is established. Figure 3.2 illustrates the research methodology adopted which will enable the research to have a better structure, to create a better understanding of the proposed framework which was developed, and to show the validity of the investigation.

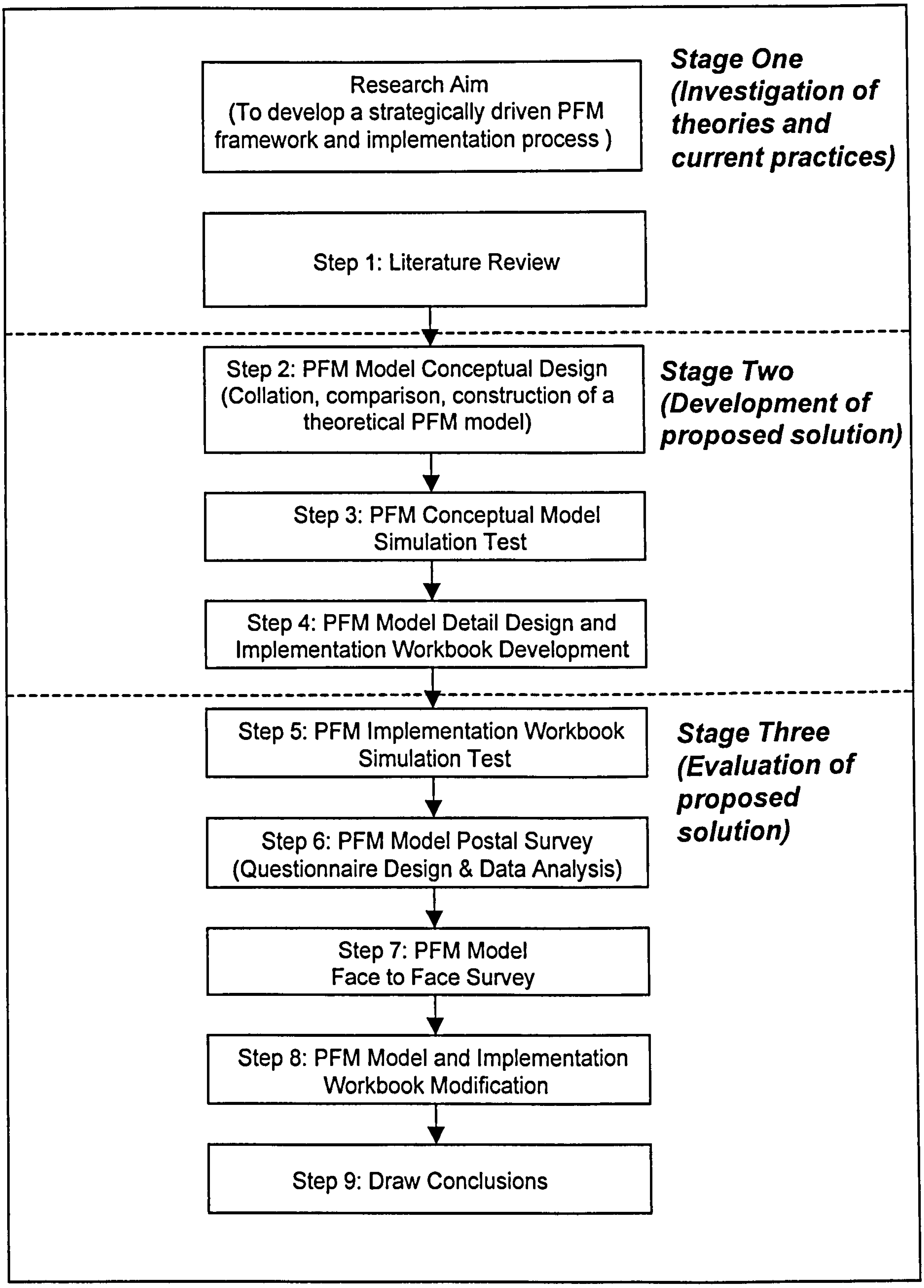


Figure 3.2 PFM Framework and Implementation Process Development Programme

There are three main stages for the research programme. Table 3.6 illustrates the research stage, objectives, and relevant methods taken in each stage.

Table 3.6 Objectives and Methods of Research Stages Analysis Table

Research Stages	*Objectives*	*Research Strategy & Methods*
Investigation of current theories and practices	1. Investigate and compare current theories and practices from existing literature and discuss relevance to the aim of the research. 2. Identify the requirements for a new approach to solve the existing PFM issues	• Exploratory (qualitative) research • Explanatory (quantitative) research
Development of proposed solution	1. Develop new method which is based on previous objectives 2. Testing the feasibility of conceptual design	• Quantitative analysis • Inter-feasibility test
Evaluation of proposed solution	1. Evaluate the new method and analyse the gap between research and practice 2. InvestigatE the wider applicability of the approach	• Quantitative analysis • Internal validity test and analysis • Questionnaire postal survey • Questionnaire interviews

3.9.1 Investigating Current Theories and Practices of Research Methodology

The first stage uses the exploratory (qualitative) research methodology to find the current management concepts involved in manufacturing strategy formulation and facilities maintenance, and to analyse their strengths and weaknesses. This stages also aims to discuss the possibility and requirements of formulating an integrated solution. This stage involved the acquisition and synthesis of information and techniques from three main sources.

Firstly, the literature; this was reviewed to discover existing relevant PFM approaches, to provide pre-design thoughts for the PFM framework and to prepare a normative theory on PFM implementation. Secondly, manufacturing companies and conferences; interviews with both line operators and facilities maintenance personnel in a number of companies through group project visiting opportunities. Participating conferences related to the subject of Manufacturing system development, facilities maintenance, ILS (Integrated Logistics Support)/CALS (Computer Aided Logistics Support) implementation, performance measurement system development and CMMS (Computerised Maintenance Management System) development. These interviews and participation in conferences provide an indication of what companies understood and implemented and the evolution of the manufacturing environment.

3.9.2 Development of Proposed Solution

The second stage aims to create the proposed solution which is based on the objectives and findings of the previous stage. Within the second stage, an internal validity and feasibility test for the conceptual model was completed (Robson, (1993) and Perry, (1996)).

3.9.3 Evaluation of the Proposed Solution

The third stage aims to test the applicability of the proposed solution and the requirement for refinement. Within this stage, an external test of the conceptual model by postal survey and face to face interviews was completed (Robson, (1993) and Perry, (1996)).

3.9.4 Establishment of the Research Programme

Based on the three proposed stages of research, a more detailed research programme was established. The purpose and context of each step, along with the implementation of the research programme, is described as follows:

1. *Literature Review – to investigate and compare current theories and practices from the existing literature and to discuss their relevance to the aim of the research. Identify the requirements for a new approach to solve the existing PFM issues.*

2. *PFM model conceptual design – to integrate the suggested techniques and methodology to develop an overall PFM framework and accomplish a conceptual design of the strategically driven PFM model. "Learning from experience – the successes and failures of the past – is one of the most important aspects of strategic management"* (Ward *et al.* 1996). The purpose of this step is to identify the requirements for improvement and the available concepts and techniques adapted from the literature survey. The objectives also include development of the hypotheses, structuring the overall process of the PFM framework, and accomplishment of a conceptual model design. Elements, gaps and omissions are identified in the development process of the model.

3. *PFM conceptual model simulation test* – The purpose of this step is to evaluate the feasibility of the "strategically driven" concept and the availability of the designed conceptual model using an example. The simulation test is also combined with the application of AHP (Analytic Hierarchy Process) theory and utilisation of the Export Choice software to help in the MCDM (Multiple Decision-Making Criteria) calculating issue. The Expert Choice software was developed by Expert Choice Inc. USA and is based on the theory of AHP.

4. *PFM model detailed design and implementation process development – Based on the conceptual model, develop a detailed framework of the PFM model and also accomplish a detailed Workbook to aid implementation.* Further developing the

conceptual model into a detailed implementation PFM model. The development of the implementation process is based on a "strategically driven" initiative and links the strategic objectives to the production facilities management decision making. In designing a strategic planning information system, Ward, et al. (1996) reported that any strategy must identify as far as possible "*where the organisation wants to be*" in the future, and also assess accurately "*where it is now*" in order to decide "*how best to get there*" given the alternative options and resources available. This research also aims to establish a hierarchical performance measurement system. During the development process, serious linking tables and matrix tables are developed to assist the decision to be made. The key activities throughout the development process also include identification of the performance monitoring measures and indicators in the PFM activity.

5. *PFM model simulation test – to test the feasibility of the prototype PFM model.* This step is the beginning of the evaluation stage. The purpose of evaluation is to assess the effects and effectiveness of some innovative interventions such as policy, practice or service. The evaluation work can be done by using experimental, survey or case study research strategies or some appropriate hybrid or combined strategy (Robson, 1993). The evaluation tasks implemented in this research are mainly: simulation test, postal survey, and face-to-face survey. A simulated operational data bank is established and input to the implementation workbook to test the feasibility of the developed model.

6. *PFM model postal survey – to validate the feasibility in practice.* The purpose of the postal survey is to understand the current practices applied in production facilities management by the manufacturing industry. In implementing the postal survey, questionnaires are used as part of the justification and validation process. The main information to be collected are the strategies, policies, possible measures and indicators used for the monitoring of business and facilities management, also the decision-making areas in production facilities management that are the concern of the manufacturers at present. The works include:

- Prepare the list of selected companies to be surveyed.

- Design a comprehensive questionnaire and post them to the selected companies on the surveyed list.
- Collect answered questionnaires
- Analysis of the collected information
- Comparison of the analysis and the laboratory simulation test. The purpose is to understand the validity of these measures and indicators.

7. *PFM model face-to-face survey – to evaluate the feasibility through face-to-face interviews and discussion.* The purpose of the face-to-face survey is to discuss the validity of the developed model and identify whether there is a gap between academic research and practical application or not. Also to discover possible actions to improve the validity and simplification of the developed model. As well as a postal survey, face-to-face interviews are used to gain the opinions of experts and practitioners in manufacturing industries. These interviews are expected to contribute to direct the model towards a more easy and pragmatic course of implementation.

8. *PFM model and implementation workbook modification – to assess the necessity of modification of the developed framework and implementation workbook.* This model should aim at serving the needs of those managers who are in charge of the facilities performance monitoring and investment decision making. Frameworks of the model should show managers how the PFM system will work, how the operational functions will be integrated and how such a PFM model will fit in to an overall management structure after validation.

9. *Draw conclusions – to draw the final conclusions.* The purpose of this step is to bring together the gap found in the literature and the evaluation results of the developed solution. The purpose is to ensure that the newly developed method will make a contribution to knowledge. This step also discusses the limitations of the research and possible improvements afterwards.

3.10 Conclusion

Chapter 3 has introduced the strategy, methodology and research plan applied in the development of the PFM framework. The following chapter will provide an overview of the conceptual design of the strategically driven PFM implementation framework.

CHAPTER 4
CONCEPTUAL DESIGN OF THE STRATEGICALLY DRIVEN PRODUCTION FACILITIES MANAGEMENT (PFM) FRAMEWORK

4.1 Introduction

This chapter describes the development of a new approach, referred to as the "strategically driven PFM framework". The primary aim of the research is to develop, test and refine a framework which would form a procedural step to support the decision-making analysis in PFM. The model also aims to structure a hierarchical Performance Measurement System (PMS) to monitor the performance of existing facilities so as to predict the life cycle stage of existing facilities and consequentially assist in making decisions in maintaining, enhancing or replacing them.

As concluded from previous chapters, the integration of PFM with a manufacturing strategy will be beneficial to improve the competitiveness of manufacturing industry. A number of current practices have been reviewed, such as the process of manufacturing strategy formulation, ILS, CALS, maintenance management technology, PMS and benchmark techniques. These current concepts and techniques are complementary from their theories. If they could be merged successfully to create an implementation model, such a result should provide a substantial contribution to the improvement of the pragmatic management of existing facilities and decision making support analysis tool for any manufacturing company. This chapter will describe the integration of these philosophies, techniques, and current practices into the proposed solution.

This chapter will also provide a conceptual design of the PFM model and an overview of the requirements to establish a guideline for the development of a strategically driven PFM framework.

4.2 Conciliation of Gaps Between Current Concepts and Theories

The realisation of the proposed approach tries to conciliate gaps between current concepts and theories. The following discussion provides a briefing of them. These gaps are:

1. *The lack of a formal manufacturing strategy process to cope with the continuously changing environment*

   The environment of the manufacturing industry has been constantly changing throughout the last few decades. However, a company must formulate its own business strategy to be responsive to this fast changing environment. In order to develop a competitive strategy for manufacturing it is necessary to have a formal strategic planning process. Many articles advocate the necessity of a formal manufacturing strategy formulation process. Nevertheless, the use of manufacturing in corporate strategy as a management practice is not widespread enough (Skinner, 1969, 1996). There is still the need for a formal manufacturing strategy process to capture the strategic objectives and guide the implementation process. In the process of implementation, there is a need to develop performance measures to monitor the performance of the business and enhance its ability to cope with the changing environment of the market. The PFM framework is a facilitator in implementing manufacturing strategy.

2. *The lack of linkage between the facilities management and strategic requirements*

   The management of production facilities mainly deals with the decisions of maintaining, enhancing or replacing existing facilities. Maintenance of the existing equipment is the first priority amongst the above three considerations. Nevertheless, there are many other factors which will influence the final decision in practical operation. It always happens that the facility must be replaced even though the function of it is still normal. In the real world, many facilities management decisions are made because of strategic concerns, such as the development of new technology and process, logistic issues of spare parts, new contract requirements or from total maintenance cost concerns. It can be seen from the literature review that there is still a gap between facilities decision making analysis and practically operational data application especially, there is no link with the strategic concerns. There is still a lack of a systematic, step by step process to link the strategic requirements with the facilities and equipment management data so as to make the right decision in PFM.

3. *The lack of flexible and reliable manufacturing facilities to ensure competitiveness*

The competitiveness of a business is usually determined by six competitive criteria. They are quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost/price (Maskell, 1991, Slack *et al*, 1998). The balance between these competitive criteria and all of the activities related to them formulate the manufacturing strategic requirements. In manufacturing business, the reliability, availability, and reliability of existing facilities will directly influence the competitiveness of the business. Flexible manufacturing facilities means the facilities have the ability to cope with fast changing volume or design of the products no matter whether the requirement is oriented externally by the customers or internally by the designers or production control department. Reliable manufacturing facilities implies they have the ability to satisfy the requirements of quality, delivery lead time, delivery reliability, speed, dependability and efficiency (cost). Therefore, to achieve manufacturing performance, there is a need to define the key indices with which the competitive parameters of manufacturing facilities can be measured, monitored and improved.

4. *The need for a performance measurement system to assist the facilities life cycle management.*

The main purpose of PFM is to deal with the management issues of facilities and machinery. Consequently, every piece of machinery has its life cycle of operation. The decisions on whether or not to cease the operation of these facilities and machinery depends on the assessment of the facilities' operating performance. and analysis of their historic data of maintenance. There is the requirement to develop a performance monitoring system with appropriate performance measures and performance indicators to collect the historic operational data of the equipment and to support and enhance the decision making analysis work.

5. *The lack of integration of maintenance management with the corporate strategic objectives in production facilities management.*

   The production facilities and equipment nowadays have become much more advanced, complicated and also easily break down. More and more companies have realised the importance of maintenance. The proper management of maintenance will not only ensure the facilities and equipment do their job when required but the savings from the cost of unplanned maintenance contributes to the total profit of the company.

4.3 Objectives of the Development of PFM Framework

In order to accomplish the aim, there are two objectives in this research. They are:

1. ***PFM framework***: Development of a strategically driven PFM model to monitor the performance of production facilities. The developed framework can be used as a tool to assist the life cycle assessment and decision-making support in maintaining, enhancing or replacing existing production facilities.
2. ***PFM implementation workbook***: Development of a step by step implementation workbook based on the developed model. The main contribution to the knowledge is the development of a Performance Measurement System (PMS), through a set of linking tables to translate the strategic requirements into the subordinate initiatives of the operational level.

4.4 Main Subjects Covered in the Research

The main subjects covered in the PFM framework developed include:

1) Manufacturing strategy formulation methodology

2) Product and facilities life cycle assessment methodology
3) Logistic engineering management and integrated logistics support technology
4) Maintenance management methodology and relevant techniques
5) Performance measurement system development methodology
6) Decision making requirements and relevant techniques

An overview diagram illustrates the relationship between these main subjects, which is shown in Figure 4.1.

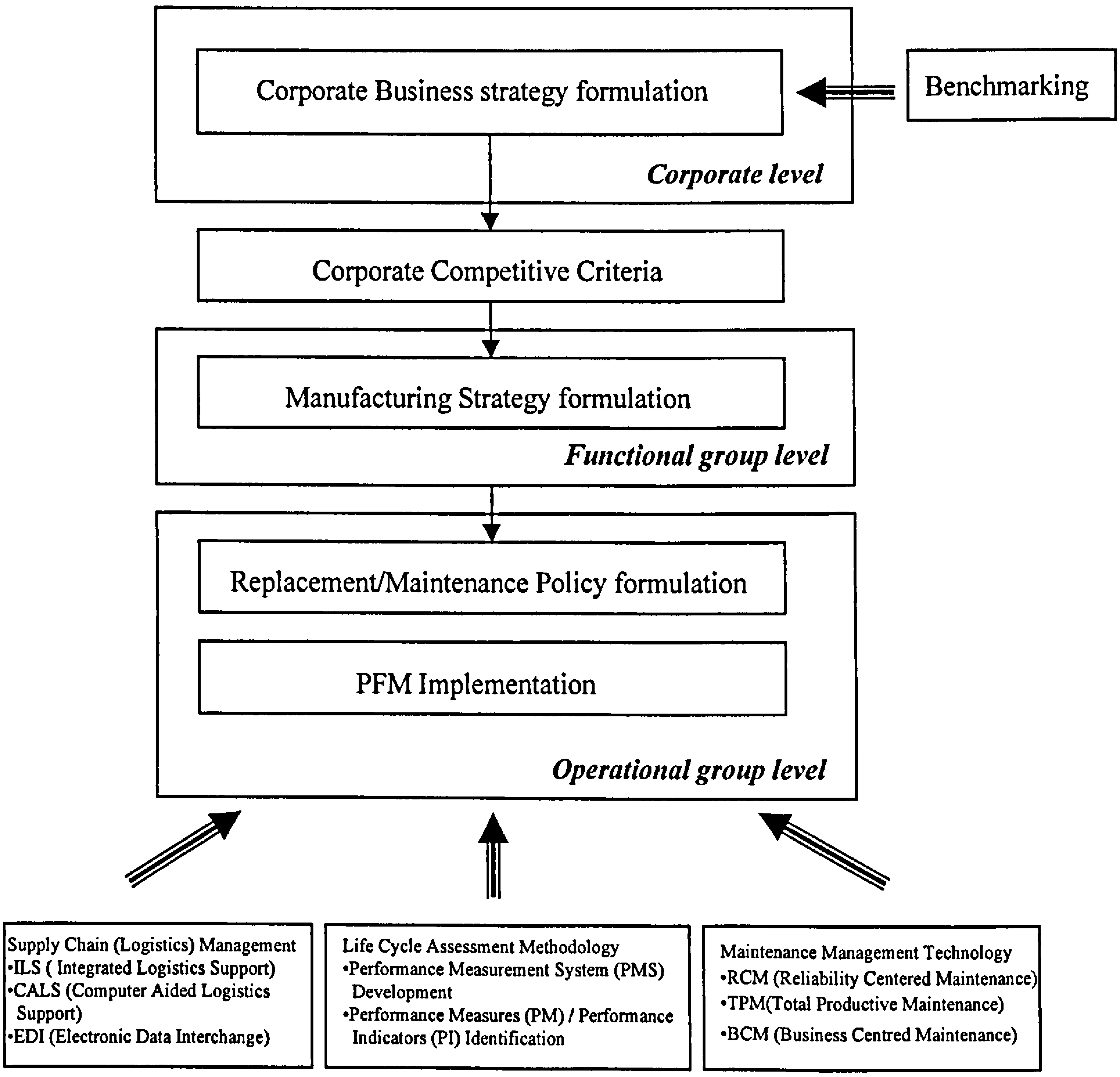


Figure 4.1 Main Strategy Contents in PFM Development

The significance of each subject is described as follows:

1) *Manufacturing strategy formulation methodology* – The manufacturing strategy formulation process involves the strategies and implementation work plans of the three levels in an organisation, the corporate level, functional level and operational group level. The strategy formulation process is initiated from the benchmarking process of the whole environment, so as to establish the corporate strategy, then sequentially developed into supporting strategy from functional level (manufacturing department management) and operational level (production line). The competitive criteria are sequentially developed and used during the formulating process, so as to monitor the performance of the business and the operational line as well.

2) *Product and facilities life cycle assessment methodology* – Based on the theory that every product or facility has its own life cycle, the research is also focused on the methodologies and techniques to monitor the changing life cycle of any product and the facility. The solution is to establish a Performance Measurement System (PMS) to track, record and analyse the performance data of different levels in a company's hierarchy. The performance measurement tree consists of the performance measurement requirements in three levels of the organisation, these being corporate level, functional level, and operational level. These PM and PI are derived from the performance of the corporation on the competitive criteria, i.e. quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost. The Performance Measures are those parameters used to represent the performance of the functional level. The Performance Indicators are those parameters used to represent the performance of the operational level. The key point is to identify what Performance Measures (PM) and Performance Indicators (PI) should be used to assist the assessment of the performance of different level. The development of a PM/PI matrix to describe the relationships between them will be discussed and structured to achieve the life cycle assessment target.

3) *Supply chain (logistics engineering and support) management technology* - The studying of supply chain management is focused on the logistic engineering and logistics support management after the facility is installed. The solution is integrating logistics support throughout the life cycle of a product and facilities.

The key activity is identifying the parameters used to monitor the operating performance of facilities.

4) *Maintenance management methodology and relevant techniques* – The relevant maintenance methodologies and techniques discussed in the literature review also provide the basis for facilities management, especially the PM/PI development and identification. The parameters developed on these methodologies and techniques also integrated into the matrix of performance measurement.

5) *Performance measurement system development methodology* – The integration of historic maintenance data and strategic objectives should be linked through this performance measurement system. The establishment of a performance measurement system provides a basis for the decision-making analysis.

6) *Decision making support techniques* – Some of the decision making support techniques such as UV calculation, AHP application, Weibull analysis, and QFD have been discussed in the literature review. How to apply them into the PFM model design is accomplished and included in the implementation workbook.

4.5 Overall PFM Process

In general, the corporate strategic plan defines the context of the facility plan. What is important is that the corporate and facility strategic plans be considered simultaneously. Hornik (1993) stated that to increase competitiveness and financial return, it is important to link organisational strategy with facilities. Teichloz *et al* (1995) suggested a model to consider the strategic facilities plan hierarchically. Teichloz's model does not provide detailed step-by-step implementation process but a generic rule to form a strategic facilities plan. First the company consider the corporate mission and its facility implications, then the company determines available resources, The company then develops a strategic plan, calculates cost and benefits, and finally defines a strategy for implementing the plan. Based on the results of literature and integration of the above subjects discussed in section 4.4 of this chapter, the proposed overall PFM process is shown in Figure 4.2.

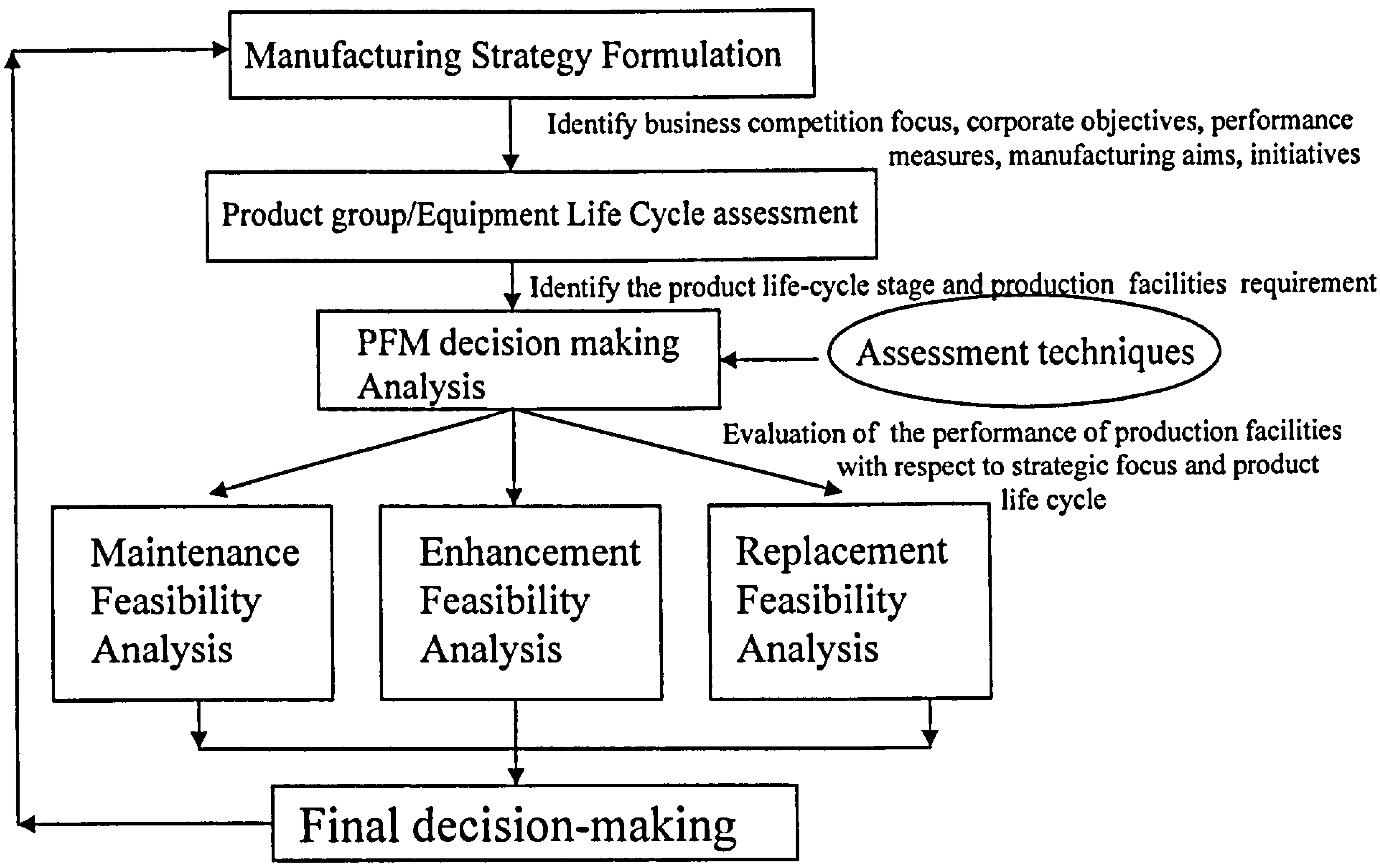


Figure 4.2 Overall PFM Process

There are three key elements in the overall PFM process: Manufacturing strategy formulation, Product and facilities group and life cycle assessment, and PFM decision-making analysis.

The PFM process is initiated from the identification of the corporate strategic objectives to the facilities management feasibility analysis in the end. The whole process is developed top-down and the driving factors are the strategic objectives. However, the system is implemented bottom-up which means the operating data are collected from the production line and they are fed back to the top management for comparison with the strategic objectives. The result of the comparison provides the basis for the decision making.

Manufacturing Strategy Formulation

From the literature review, it can be seen that the manufacturing strategy is gaining increasing attention from academics and management alike because it articulates focus and direction and therefore provides a reference from which to gauge new technologies, systems and ideas. Above all, a company must formulate a management strategy that is fitted to its own organisational structure so as to be responsive to cope with the fast changing environment. A number of articles have been discussed in the previous chapter regarding the process of manufacturing strategy formulation. The formulating process for the objectives of a manufacturing strategy can be determined by the perspectives of six competitive criteria. They are quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost/price. The decision-making process involved to prioritise these criteria and all of the relevant plans and activities to be implemented constitutes the corporate strategy and policies for different management levels in the corporate hierarchy. PFM is one of the key activities in implementing corporate strategy in particular for manufacturing and supply system management.

The output of a manufacturing strategy formulation is the identification of business competition focus, corporate objectives, manufacturing aims, and manufacturing initiatives. During the process of strategy formulation, the measures for benchmarking the performance of achievement are also decided.

Product Group / Equipment Life Cycle Assessment

The meaning of product/equipment life cycle assessment is to capture the current situation both of the products and the facilities to produce these products. The decisions of whether or not to cease the operating age of these facilities and equipment are influenced by the operational performance of existing facilities. To make a right decision on facilities depend on the correct data which is generated from an appropriate data collecting and analysis system. However, the decision of what PM and PI can be used to assist the assessment is very important. In general, these operational data are collected through the historic data of maintenance of the production facilities.

PFM Decision Making Analysis

The decision making process in implementing PFM is difficult because it involves the analysis of large amounts of operating data. The functionality of PFM decision making aims to establish a hierarchical structure of the factors involved in decision making and the process of analysing them.

4.6 Specifications of a Strategically Driven PFM Model

Based on the overall PFM process, the following are especially required to be the specifications of PFM model development:

1. ***Coherent with the corporate and operational strategies***: The objectives adopted at various levels of the organisation must be coherent with the overall business objectives. A facility investment is evaluated in terms of its impact not only on the performance of any new or modified facility but also on the overall performance of the firm's other facilities. The facilities plans should be integrated with long-term strategies i.e. the capacity / facilities decision process should be strategy-driven so as to be carried out and their coherence guaranteed to meet the corporate strategic objectives (Hays *et al*, 1984). The capture of the business and operational objectives is also an essential function in the model design.
2. ***Adequate measurement of the operation and implementation process***: To facilitate an effective plan and to control the performance for the total business and operational achievement, the model should have the ability to measure the operational process with adequate parameters. The right measures will help the team excel. The proper measures and indicators for the decision-making process should be included so as to understand the current performance of the business and facilities and make subsequent decision-making to correct the deviation just in time. The concept of performance measurement in managing existing facilities is one of the main areas in this research. This area studied the approaches of the philosophy, utilisation and theoretical aspects of performance measurement system development in monitoring the business and also the facilities for production. The design of a performance monitoring system for PFM is based on the application of a competitive benchmarking methodology and the maintenance concepts and procedures. The establishment of a sequential process to monitor the operation performance is required.

3. ***Adequate control of the facilities performance improvement:*** In order to survive in the market, the PFM model must have the ability to benchmark the changing of the manufacturing environment, in particular the ability to cope with the challenge from external competitors. The gap analysis, an improvement action plan and monitoring project should be established so as to assure the implementation of improvement plan would continuously respond to the market situation and corporate strategy.

4. ***Adequate assessment technique application:*** In order to simplify the complexity of the decision-making process, the available assessment and analysis techniques should be reviewed and applied in the model. The proper techniques help in the analysis of the priority of the strategic objectives and the targets for improvement.

5. ***The translation and link between business performance measurement and production facilities performance assessment:*** For the development of an optimal Production Facilities Management framework, a systematic procedure for the formulation of maintenance/enhancement/replacement strategy for industrial plant is necessary. It is driven throughout by the identification of primary business objectives and their translation into PFM objectives and the application of proper links between them. In the designed model, the final decision of PFM is amongst the options of maintaining, enhancing or replacing existing facilities.

4.7 Application of Manufacturing Strategy Formulation in Development of PFM Framework

Cheng *et al* (1997) concluded that integrated and agile manufacturing is the future. The nature of the work required within the operation system must, necessarily, be a function of the policy of the organisation. This viewpoint highlights the fact that the policy decisions on product/services will determine the requirements of the operation system. Further policy decisions on the way in which markets are to be served, e.g. the importance of cost, will influence operations objectives, in turn influencing the way in which work is done in the system (Wild, 1995). Corporate strategic objectives, manufacturing aims, initiatives, operational objectives, and action plans must be dependable, consistent and coherent. Figure 4.3 demonstrates the relationships between them. Resource utilisation includes both the hardware maintenance management and software management, being the most important activity in the operations objectives.

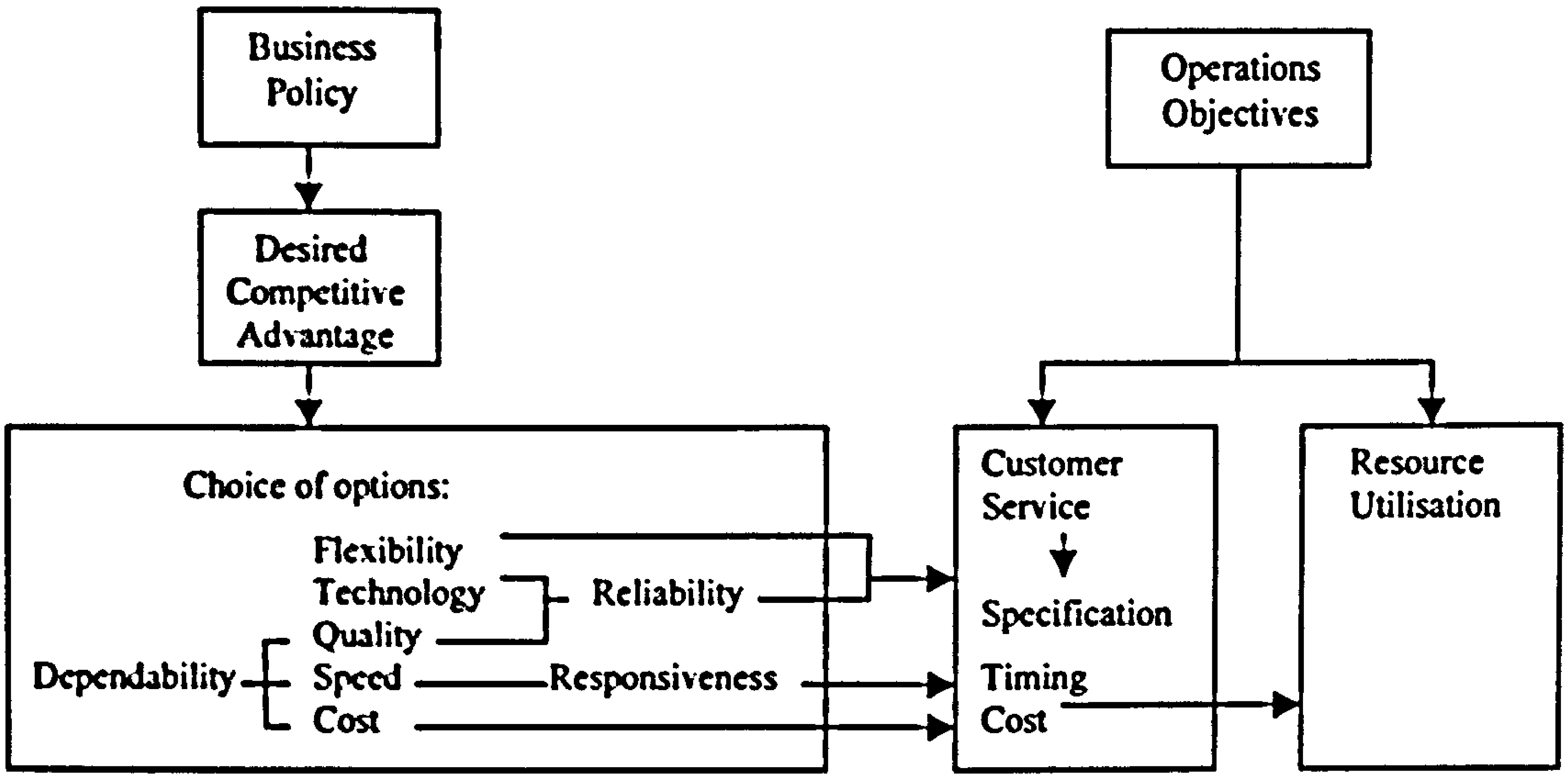


Figure 4.2 The Linkage Between Business Policy, Strategic Objectives and Operations Objectives
(Source: Wild, 1995)

Reference to the above model, which focuses the linkage between policy objectives for the manner in which markets are to be served, and operations objectives on customer service reveals the following possible business policy/work design relationships. This model presents the possibility of translating the business policy into operational objectives through an agreed choice of policy options on quality, technology, flexibility, speed, cost, reliability and responsiveness as shown in the model.

4.7.1 Application of "Strategically-Driven" Concept

In industrial practice, Darlow (1999) investigated the role of formal planning progress in manufacturing strategy formulation and concluded that a formalised approach to formulating manufacturing strategy can improve the effectiveness of the business. Darlow (1999) also synthesised the steps of the theoretical formal planning process for a manufacturing strategy as follows.

1. *Define corporate objectives*
2. *Select product families*

3. *Audit of external conditions*
4. *Audit of internal capabilities*
5. *Gap analysis between actual and designed performance*
6. *Prioritise key issues and define objectives of manufacturing*
7. *Synthesise and choose manufacturing strategies*

The strategic objectives were captured through a strategy formulating process and they function as the drivers for following the PFM implementation process. Wu and Ellis, (1998a), and Wu and Chang, (1998b) proposed a concept of "strategically driven" for the development of manufacturing systems and the decision making of the choice of ERP (Enterprise Resource Planning) system. Both papers proposed a similar "strategically-driven" sequential manufacturing strategy formulation process as shown in Figure 4.4.

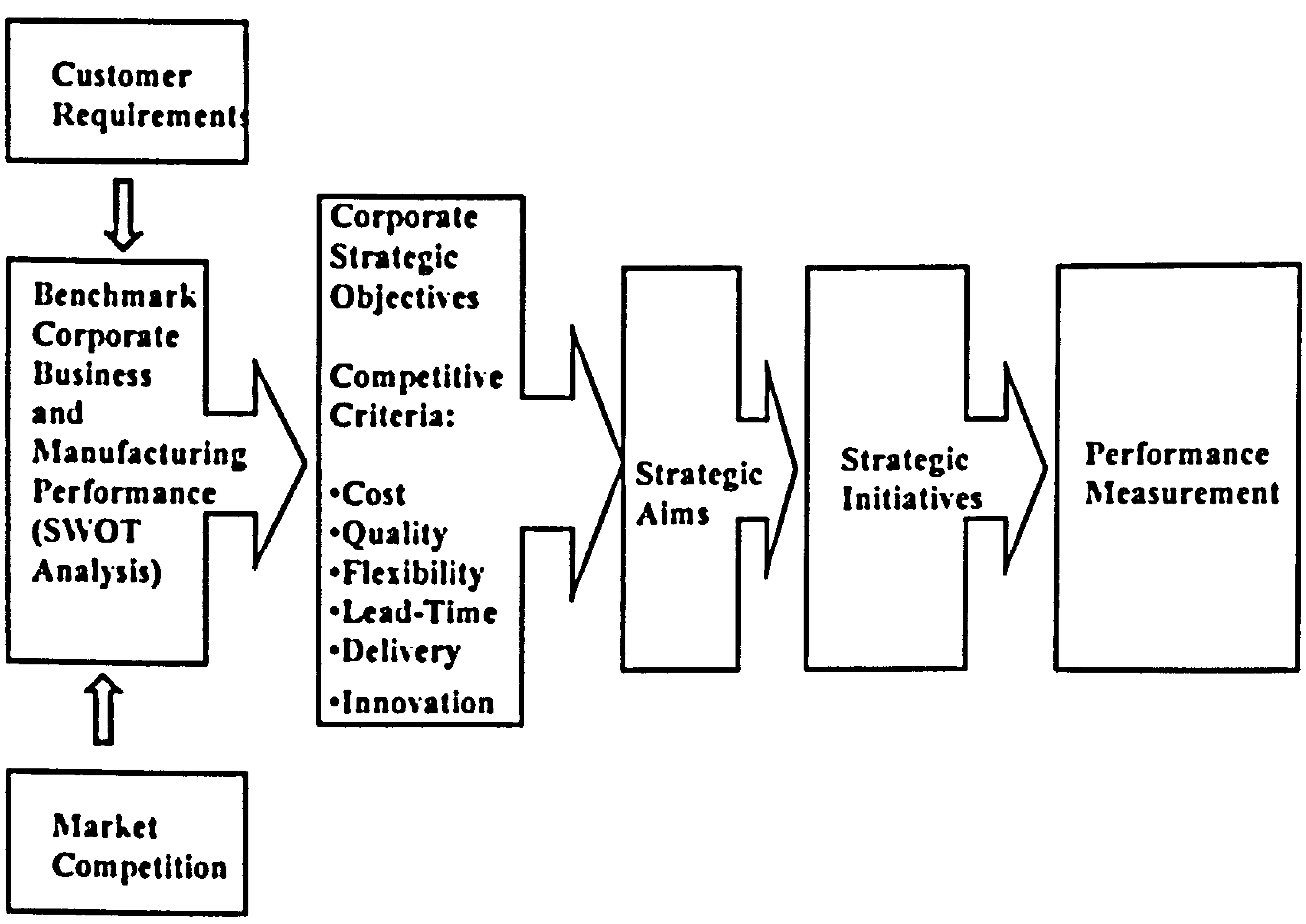


Figure 4.4 Manufacturing Strategy Formulation Process

(Source: Wu et al 1998a, and 1998b)

The stage of manufacturing strategy formulation is initiated from benchmarking the business performance internally and externally through SWOT analysis to find the strengths, weaknesses, opportunities and threats of and to the company. According to its business status, the company can develop its strategic objectives based on these competitive criteria such as quality, delivery, cost, flexibility, and speed. Sequentially manufacturing aims and initiatives are decided. During the formulation process, the priority of these competitive criteria and performance measures for benchmarking the achievement of them are also decided. Even though they do not propose the detailed implementation plan and the process to benchmark the operational performance and strategic requirements for the improvement of a manufacturing system; the process highlights a "strategically driven" concept in generating strategic objectives and capturing the manufacturing aims and initiatives.

With a similar "strategically-driven" concept, Hull (1998) developed a more comprehensive investigation into the implementation process of formulating manufacturing strategy and looked into the issue of the interface issues between these strategic objectives and the steps needed to generate the improvement initiatives with an implementation workbook. Hull's study was focused on the interface of manufacturing system analysis and manufacturing system design. However, his study is not detailed enough to search for a process to monitor the operational performance during manufacturing system operation. There is still the lack of a tool for the linkage of production facilities performance and strategic objectives.

All of these previous works illustrate the application of the concept of "strategically driven" on the PFM framework.

4.7.2 Application of Manufacturing Strategy and Maintenance Management In PFM Framework

To design the PFM framework, maintenance is the inevitable topic to be discussed.
The integration of the strategic objectives formulation and maintenance practices plays an important role in this PFM framework. This is because the collection of historic maintenance data is essential for monitoring and judging for the fate of a facility, and

many options are based on corporate strategic concerns in the end. Campbell (1995) pointed out that "*to win today's global competitive business, the dictum is – Maximise output of goods and services and minimise input of resources – financial, human, and physical.*" Campbell (1995) also stated that the relationship between business and facility performance is based on a value equation.

$$Value = \frac{Quality * Service}{Cost * Time * Risk}$$

To satisfy customers, an enterprise must respond quickly to service goods throughout their life cycle. The higher the quality and service for a given cost and response time, the more value to the customer. So the physical resources, employed equipment, fleets, facilities or plants – must be available when needed, and must produce at the required rate and quality, all at reasonable cost. Environmental and safety risks must be minimised. Whether the integration of business strategy and maintenance management will increase the competitiveness of manufacturing has recently been discussed by several researchers, such as Raouf *et al*, (1993), Labib (1996, 1998), and Kelly (1997). Figure 4.5 shows one of the integrated maintenance models which was developed by Campbell in 1995.

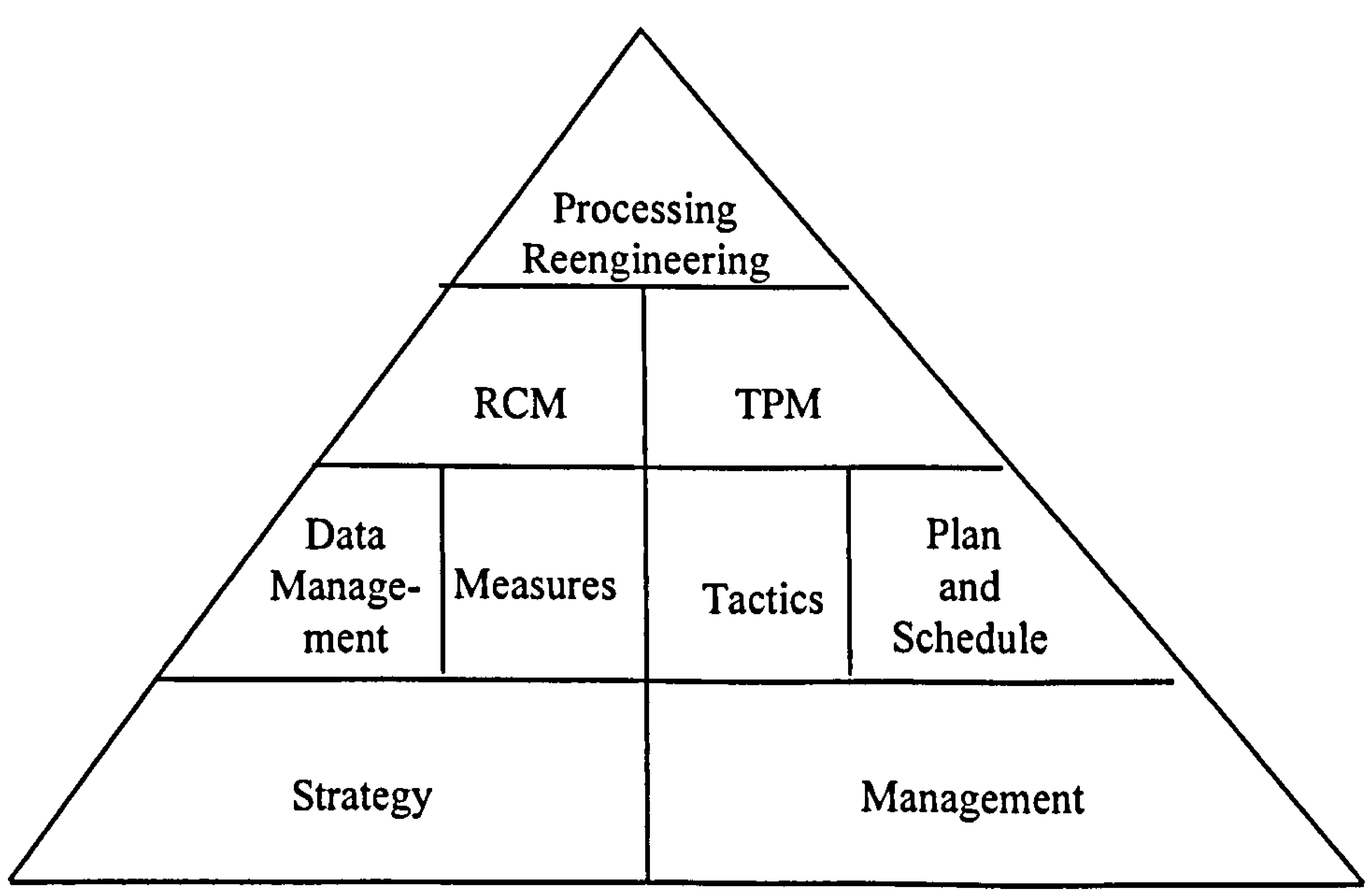


Figure 4.5 World Class Maintenance Model
(Source: Campbell, 1995)

The proposed model integrates the requirements of corporate strategy, management and the maintenance management methodologies, i.e. TPM, and RCM together, to optimise the uptime of the assets. In this conceptual model, he has highlighted the importance of the integration between these latest maintenance practices and the strategic requirements from the business perspective. In developing the maintenance strategy, Campbell (1995) also proposed the model as shown in Figure 4.6.

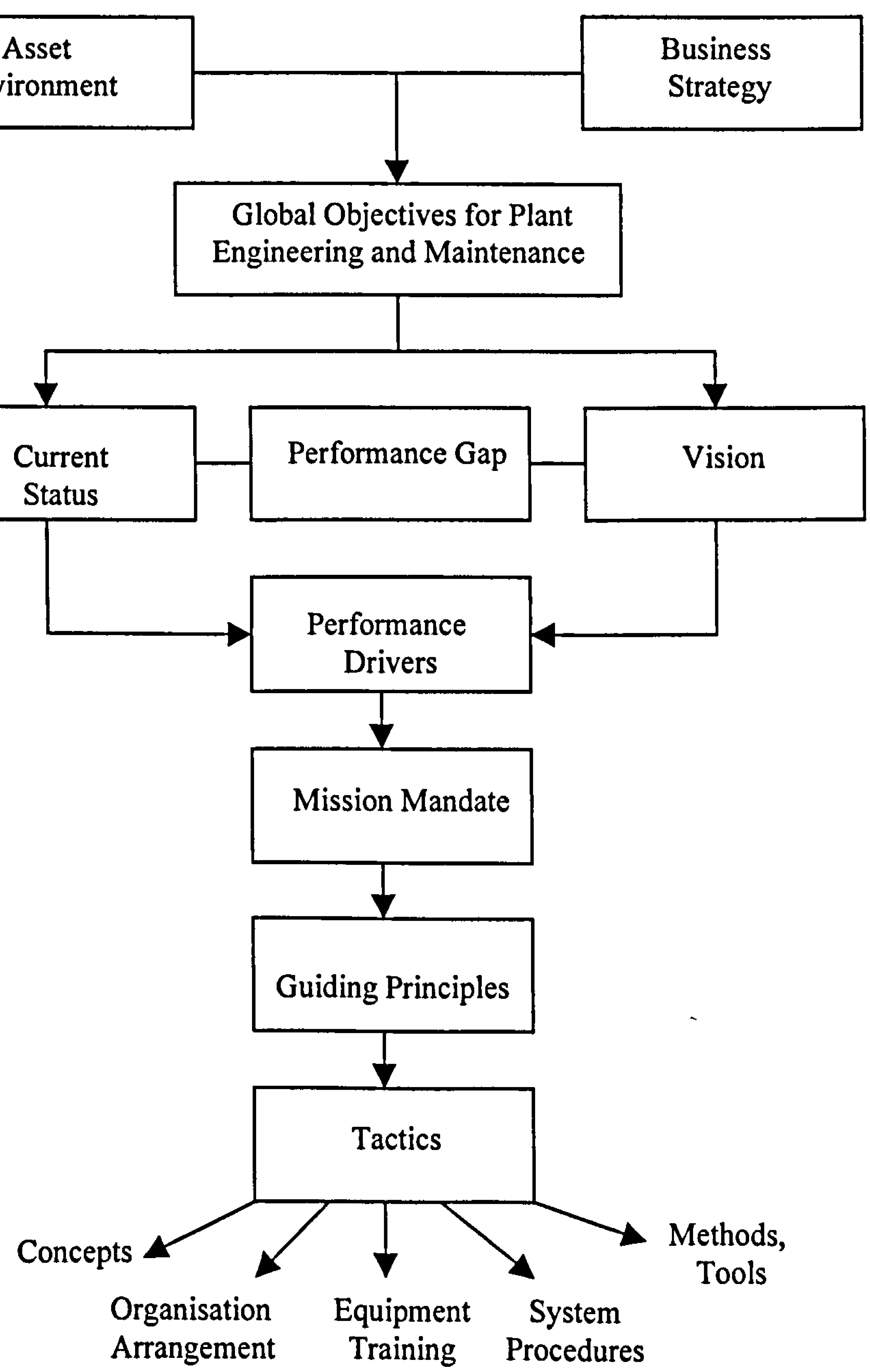


Figure 4.6 Maintenance Strategy Model
(Source: Campbell, 1995)

In Figure 4.6, the maintenance strategy is oriented from the needs and wants of the customers and shareholders in any business plan. The key objectives for successful maintenance of equipment is narrowing the performance gap between the current status and business vision as much as possible. The performance drivers and mission statement of the corporation must be compatible. The solution for a proper maintenance strategy is an integration of business strategy and implementation of guiding principles to link tactics and strategic objectives. Even though Campbell did not mention a detailed implementation plan, he has highlighted that the maintenance usually operates alone, and it should be strategically driven. All of this research and theories support one of the specifications that the PFM framework should be coherent to the corporate and operational strategies.

4.7.3 The Major Concerns in Integration of Maintenance Management Technology and PFM Framework

The implementation of the management of production facilities and equipment depends on the application of the maintenance concepts and the procedures of a maintenance plan. Companies have tried different organisational structures, changing reporting structures, upsizing, downsizing, contracting out, and empowered teams in an attempt to control maintenance. Yet, the majority of companies have not been able to manage maintenance. The two largest factors contributing to this have been the lack of proper measurement and the lack of control systems for maintenance (Wireman, 1998). For a complex manufacturing system consisting of sub-assemblies, components, and parts, it is necessary to determine the following (Ebeling, 1997):

(1). *"Which units are to be repaired rather than discarded and replaced."*
(2). *" The preventive maintenance schedule and associated works."*
(3). *"For repairable units, the level of repair (such as local, service centre, or factory)."*
(4). *"For each repair work, the required skill levels, tools, test equipment, technical manuals, and relative engineering supports."*
(5). *"The number of repairing channels and spare parts acquisition."*

The economic trade-off between repairing and discarding is normally the first parameter to be considered. For each component and part of the equipment, there are three alternatives: fully repairable, partially repairable and non-repairable. Partial repair ability implies that certain failures happened where it is not economical to initiate a repair action. Instead, a replacement action might be taken to fix the failure back to the normal performance requirement. For a repairable unit experiencing wear-out at some point in its life cycle, the continuing cost of repair might exceed the replacement cost. Preventive maintenance may extend the useful life of the unit, in which case the plan of performing preventive maintenance must be established.

The determination of the level of repair is often an economical decision that considers the required skill levels, tools, test equipment, technical manuals, and relative engineering supports.

At the lowest level repair is often accomplished by the organisation on site with operators frequently performing maintenance tasks. In this case, the repair may consist of minor maintenance, removal and replacement, and routine servicing and adjustment.

At the intermediate level of repair, a centralised repair centre is required. Maintenance personnel are employed specifically to perform repairs who have higher skill levels than those servicing in the lowest level. Repairs may be performed on removable components or on the system itself.

The highest level of repair may be performed at the manufacturer's or contractor's factory, or in the case of military service, at a specialised depot. Normally, this kind of repair is only performed on the costly, complex components requiring very specialised skills, repair equipment and tools, or critical alignment. Overhauls consisting of complete tear down and rebuilding of assembly are performed at this level.

The maintenance and supply resources necessary to support the repair process are very important. Establishing and maintaining the proper levels of these resources is often considered as part of the logistics support process. For each level of maintenance, the necessary facilities, skill levels, spares, tools, test equipment and service manuals must be identified.

4.8 Application of the Product Group and Equipment Life Cycle Assessment in PFM

Previous research on life cycle identification was introduced in the previous chapter. As noted, the product and facilities have a similar life cycle profile as shown in Figure 4.7 (Wild, 1995).

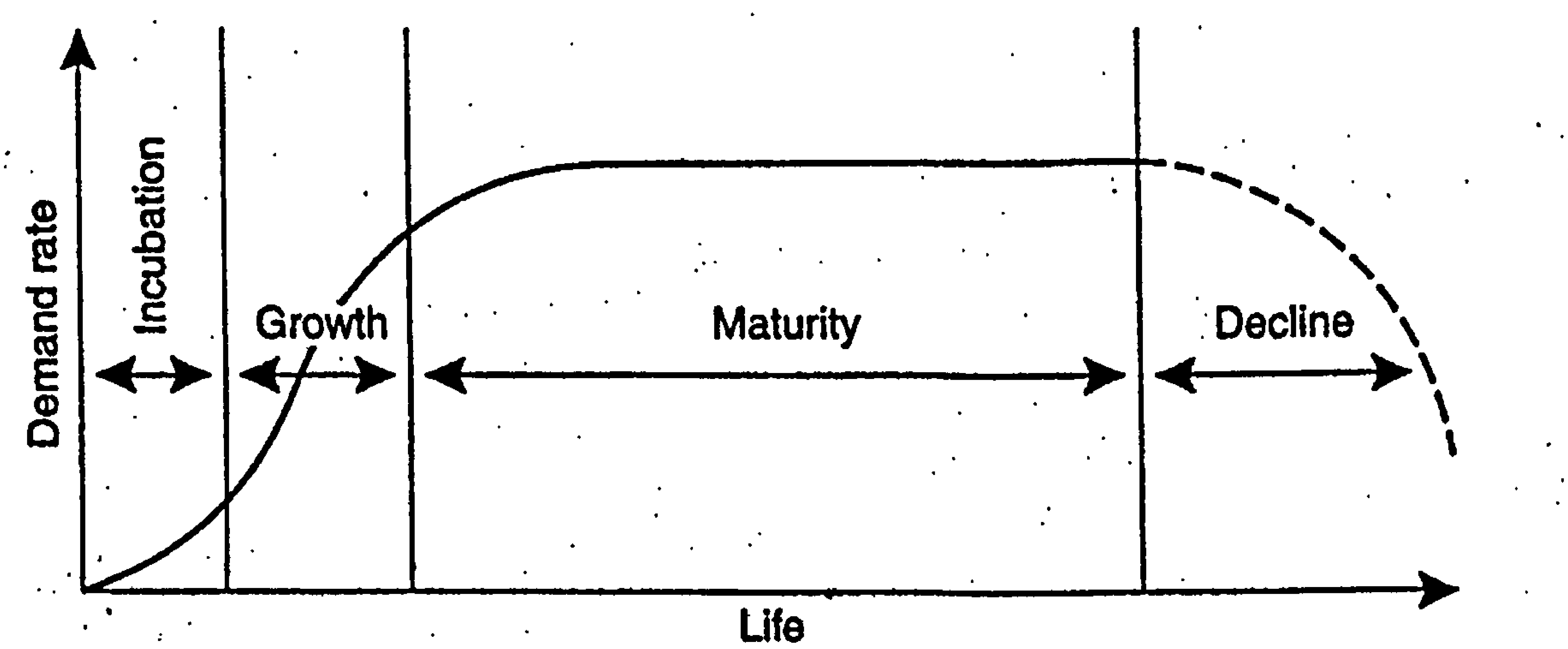


Figure 4.7 Product Life Cycle
(Source:Wild, 1995)

The life cycle of a product (group) is normally driven by the demand rate in the market. The life cycle of any facility is influenced by more factors, the capacity requirement from the production plan might be the most important one. Without demand the facility will be redundant even though the performance is still acceptable. The capacity and performance of any production facility will have much direct or indirect influence on the products and business, such as quality, delivery accuracy, flexibility of the products and cost of the business. The key point of the PFM framework is dealing with the methodology to monitor, plan and control the detail changing of the performance of existing facilities and enhancing the proper decisions to be made at the right time in their life cycle.

4.8.1 The Life Cycle of Production Facility

Fine *et al* (1985) developed a framework for formulating manufacturing strategy in an electronics firm based on the product-process life cycle (Hayes et al, 1979 a and 1979b) and the product and process innovation curve and the concept of factory focus (Skinner, 1974). Wild (1995) also developed a pretty comprehensive life-cycle model for a facility as shown Figure 4.8. This diagram indicates those activities required in conceiving, creating, providing, operating, maintaining and disposing of a physical facility and optimising the operational performance as the main target for every organisation to approach.

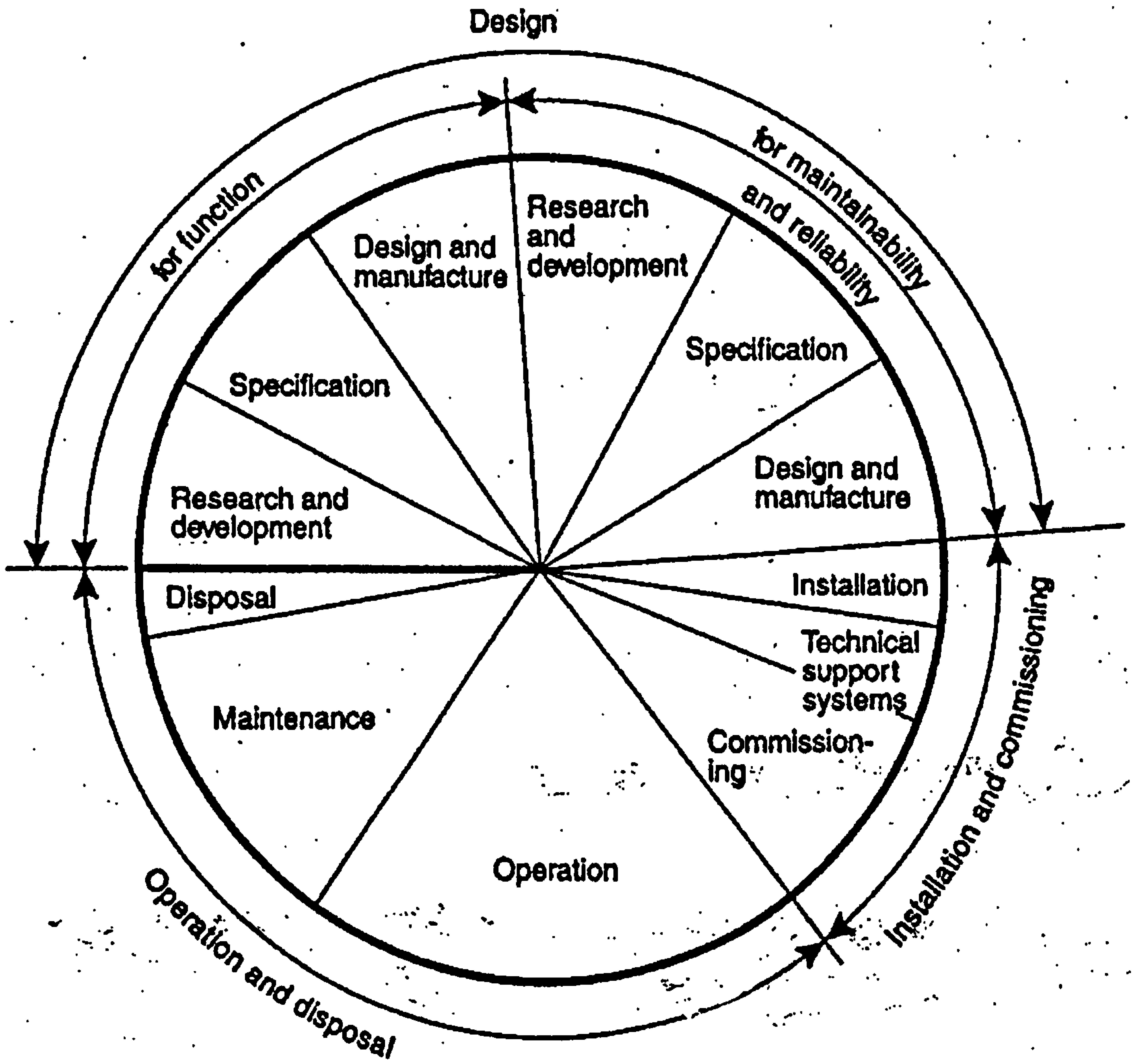


Figure 4.8 The Operating Life Cycle of a Facility

(Source: Wild, 1995)

Taking maintenance from this set, it will be seen that many decisions and an amount of maintenance are required. The design of facility, both with regard to its design 'for function' and its design 'for maintainability and reliability', will influence operation, as well as its installation and commissioning. The effectiveness of maintenance will influence the time available for and the time spent in operation. Thus the need for maintenance and the nature of maintenance required are determined by a variety of factors. The maintenance function within an organisation is therefore influenced by many other activities within the organisation. The decisions of whether to cease the operation of these facilities or not is the most important one which depends on the assessment of monitoring the facilities' operating performance and analysis of their historic data of maintenance. The decision options are normally divided into maintaining, enhancing or replacing them.

In optimising the life-cycle investment value of a physical asset, Campbell (1995) advocated a nine-step asset management process which is shown in Figure 4.9.

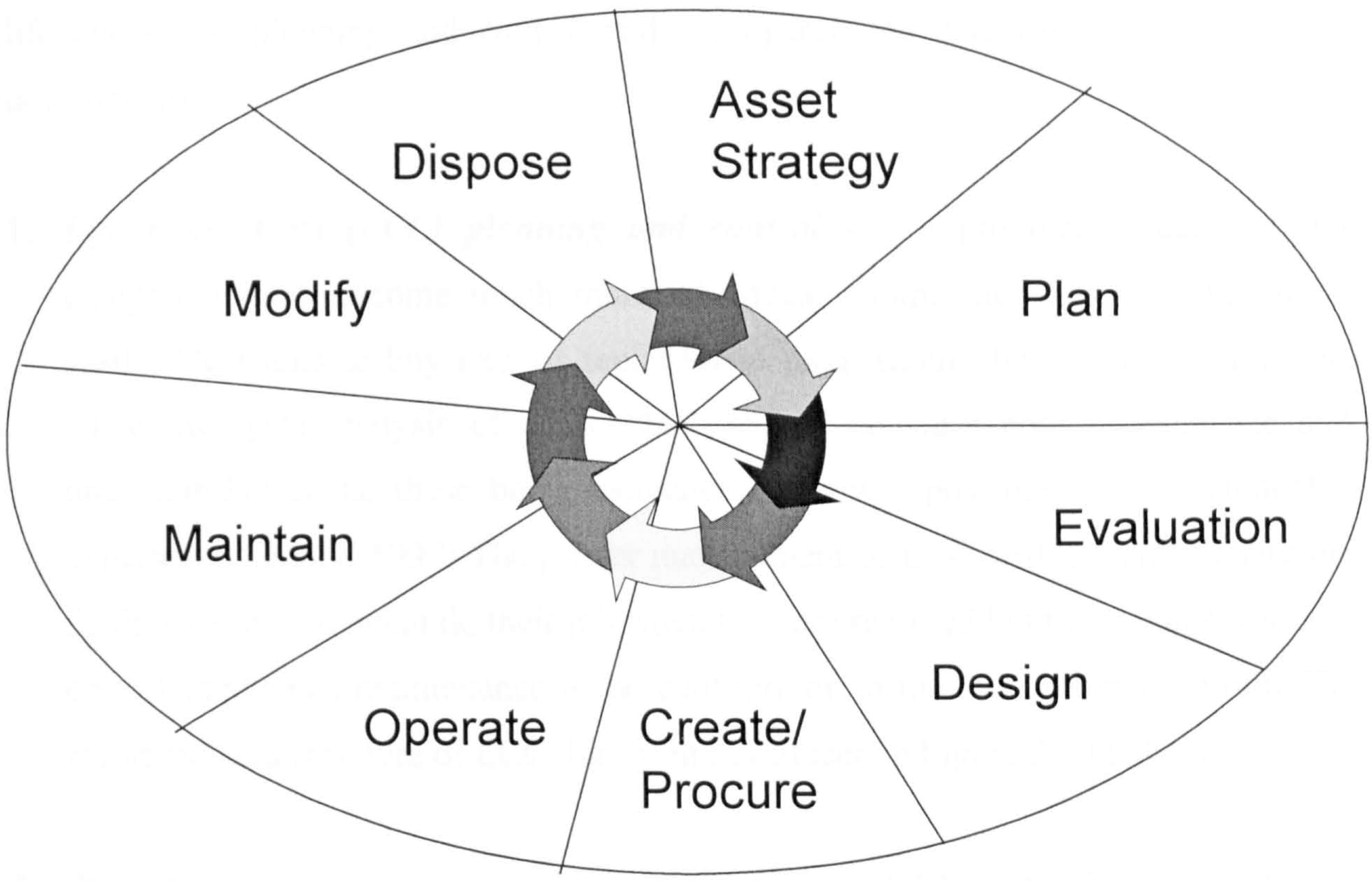


Figure 4.9 Optimising Life-Cycle Investment Value
(Source: Campbell, 1995)

Campbell's asset management process is a kind of strategically driven design, which begins by asking why the asset is required and how it relates to the business plan. After that, a closer look sets the purpose, function, and standards of performance. It is then justified; comparing costs with benefits, and ranked as an investment option by the company. After approval, detailed design and specifications are completed. The asset is constructed, or procured, and installed. Once it gets tested, it is operated and maintained, and often modified as time goes on. When the asset's usefulness is ended, it is disposed of.

4.8.2 Application of ILS (Integrated Logistics Support) and CALS (Computer Aided Logistics Support) Concepts in PFM Framework

The theories of ILS and CALS have been introduced in the literature review. The concept of life cycle support planning and control embedded in ILS and CALS provides two main initiatives that can contribute to the PFM framework design; they are life cycle cost planning and control and the operational performance measurement development.

1. ***Life Cycle Cost (LCC) planning and control*** - The production facilities and equipment have become much more advanced, complicated and also fail more easily. Decisions to buy new or replacement plant should be based on a present-value life-cycle analysis of costs which should consider both maintenance and unavailability costs, these being estimated, wherever possible, from documented experience. (Kelly, 1997) The proper management of LCC will not only ensure the facilities and equipment do their job when they are required but the savings from the cost of unplanned maintenance is the contribution to the total company profit. The recommended structure of LCC has been introduced in Figure 2.9 in chapter 2.

2. ***Operational performance measurement system establishment*** – The establishment of an appropriate PMS to monitor the operational performance throughout the life cycle of the equipment is another key element of ILS and CALS. The life cycle support analysis and plan can be started as early as the specification and design period of any equipment. The measures used for the performance monitoring and the LCC analysis structure, and the LCC centred analysis model in the PFM framework is shown in Figure 4.10.

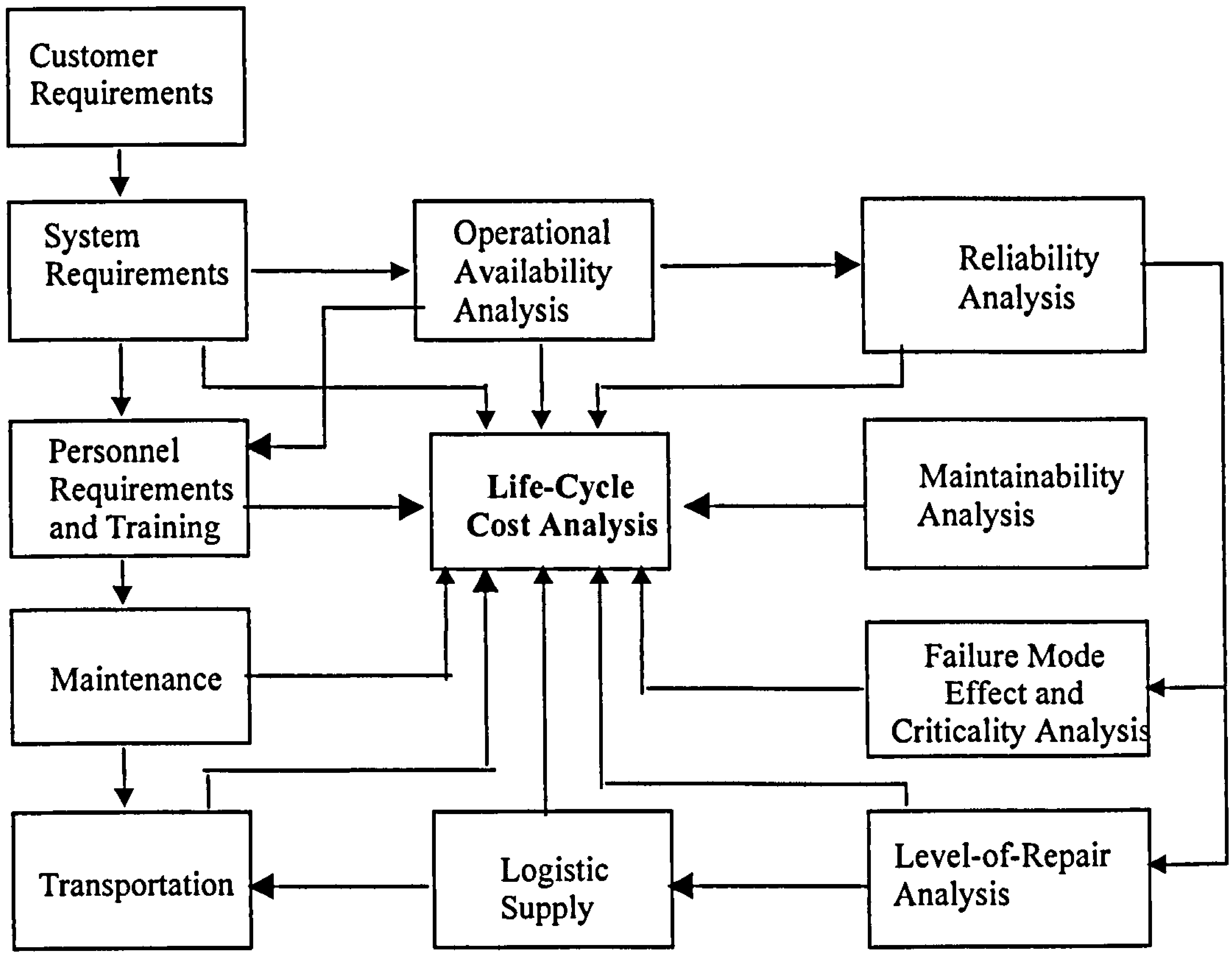


Figure 4.10 The Life-Cycle Cost Centred Analysis Model

The key performance analysis activities include:

- ***Reliability Analysis*** – Analysis of "*The probability that a component or system will perform a required function for a given period of time when used under stated operating conditions*" (Ebeling, 1997).
- ***Maintainability Analysis*** – Analysis of "*The probability that a failed component or system will be restored or repaired to a specified condition within a period of time when maintenance is performed in accordance with prescribed procedures*" (Ebeling, 1997).
- ***Availability Analysis*** – Analysis of "*The probability that a component or system is performing its required function at a given point in time when used under stated operating conditions*" (Ebeling, 1997).
- ***Failure mode effect and criticality analysis*** – Analysis of the causes of the failure and the effect of the failure on safety and availability afterwards.

- *Level of repair analysis* – Regulation of the repair policies of the facilities to be non-repairable, partially repairable or fully repairable and the required levels of maintenance amongst the options of organisational maintenance, intermediate maintenance or depot maintenance.

The LCC is influenced by the reliability, maintainability, and availability characteristics of any facility (Smith, 1997). There are many parameters available for these characteristics of any facility. These detailed parameters are also used to benchmark the performance of a facility and some typical ones are developed and specified in the PFM implementation workbook, as seen in Appendix C.

4.9 Development of PMS (Performance Measurement System) for the PFM Framework

The real test of this PFM framework is converting it to reality. Even the most elegant and perfect strategies are of no value unless they are implemented. The significance of strategic leadership is to work through people to implement the strategic initiatives to achieve the strategic aims (objectives). The function of PMS is to provide a tool for the assessment of the achieved performance and to prepare for the following improvement plan if it is required.

4.9.1 Hierarchy of a PMS in PFM Framework

Consistency and congruence of the corporate strategic requirements with the performance of implementing them is the vital factor of a successful corporation. To develop strategically driven PFM performance measurement system, the establishment of a hierarchical structure is one of the tasks to be accomplished. Ghalayini (1996, 1997) proposed an Integrated Dynamic Performance Measurement System (IDPMS) framework, which integrates three main functional areas of the company; they are management, process improvement team, and factory shop floor control. To achieve an integrated system, these three areas are linked through the specification, reporting and dynamic updating of the defined areas of success, performance measures, and performance standards. Adapted from the hierarchical concept of an IDPMS framework, a recommended hierarchy for the strategically driven PFM PMS is formulated as shown in Figure 4.11.

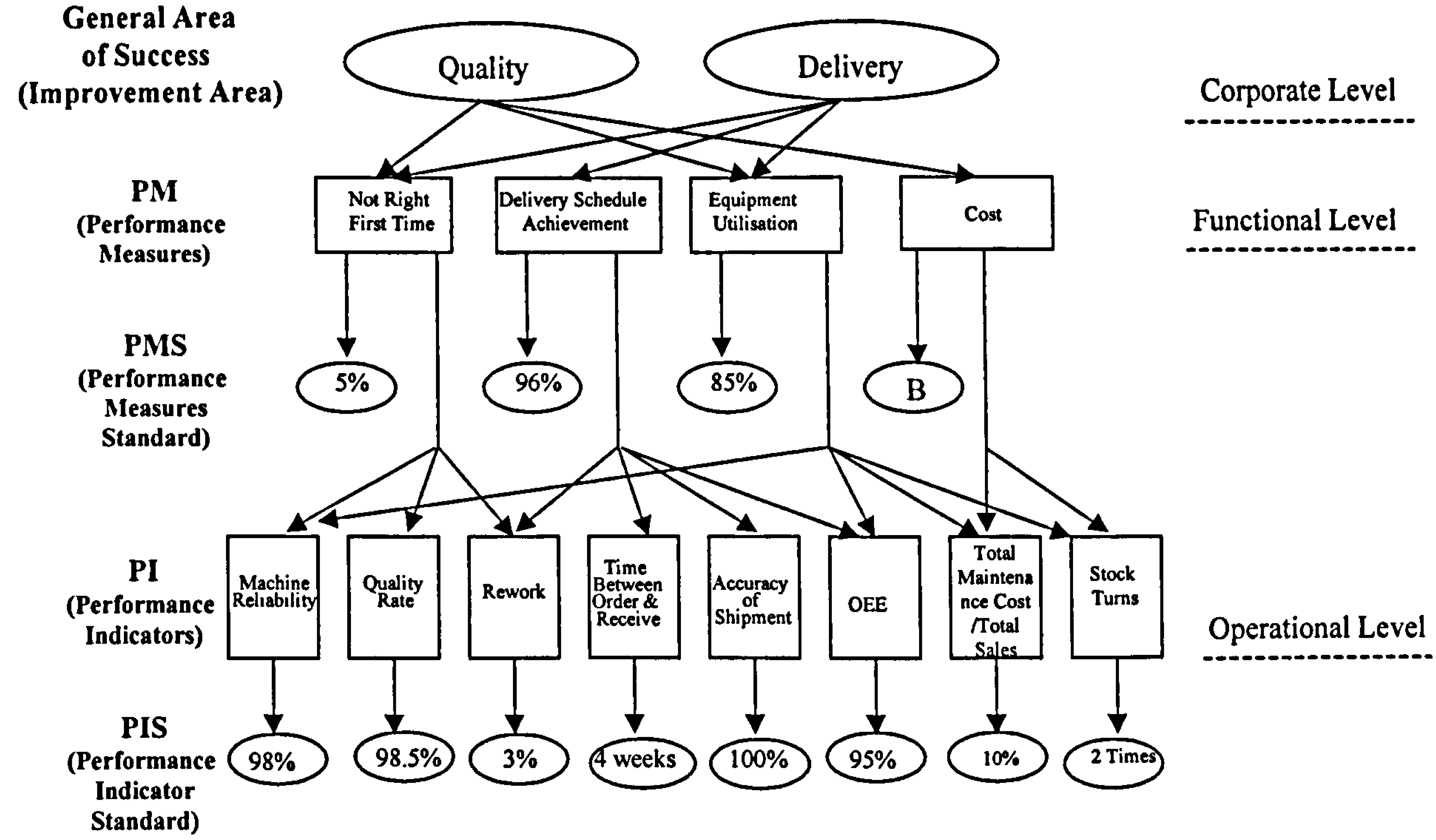


Figure 4.11 Performance Measurement System Tree in PFM
(Source: Modified from Ghalayini, 1997)

This diagram shows the hierarchy of the different activities within the organisation and supports the notion that these activities should be measured, controlled, and improved in order to achieve the stated strategic objectives (e.g. reliable delivery). The performance measurement system tree in PFM consists of the performance measurement requirements in three levels of the organisation, these being corporate level, functional level and operational level. Figure 4.12 also shows how the performance measures and the performance indicators for different areas of success are related. Identifying the interactions between the different performance measures and performance indicators helps the company determine how to improve the performance of several areas of success by focusing on one performance indicator. The hierarchy of the system also specifies the methodology to translate the strategic objectives (general area of success) into the requirements of implementation in the operational level (performance measures and performance indicators). In this research, a PM/PI convertible matrix is recommended and specified in Appendix H (refer to page 365 to page 368) which is also applied in the PFM implementation workbook of Appendix D (refer to page 321 to page 324 of the thesis).

4.9.2 Development of Performance Measurement (PM) and Performance Indicators (PI) in PFM PMS

The establishment of an appropriate Performance Measurement System (PMS) to assist the implementation of PFM is one of the key activities in this research, because *"You can't manage what you can't measure"* (Zairi, 1996). Performance measurement takes place through a methodological approach which is the key determinant of the effectiveness of the PFM framework. An appropriate measurement system is one which provides high quality information that will lead to action and things being changed.

In measuring and benchmarking equipment performance, there are many parameters available: availability, reliability, maintainability, quality and safety characteristics of any facility. In any particular case, there is likely to be one parameter more appropriate than the others. These detailed parameters are developed and specified in the PFM implementation workbook, Appendix D. Here are some commonly accepted terms and definitions to be commonly utilised that are suggested by Campbell (1995), Ebeling (1997), Smith (1997), Wireman (1998), and Sekine, *et al* (1998). They are:

- Availability – A measure of uptime, as well as the duration of downtime. It is calculated as:

$$Availability = \frac{Scheduled\ time - All\ unplanned\ time}{Scheduled\ time}$$

- Reliability – A measure of the frequency of downtime, or mean time between failures (MTBF). It is determined by:

$$Reliability = \frac{Total\ operating\ time}{Number\ of\ failures}$$

or

$$Reliability = \frac{Total\ operating\ cycles\ (km,\ tons)}{Number\ of\ failures}$$

- Maintainability – A measure of the ability to make equipment available after it has failed, or mean time to repair (MTTR). It is determined by:

$$MTTR = \frac{Total\ downtime\ from\ failures}{Number\ of\ failures}$$

- Process rate – A measure of the ability to operate at a standard speed or cycle. It is calculated by:

$$Process\ rate = \frac{Ideal\ cycle\ time}{Actual\ cycle\ time}$$

- Quality rate – A measure of the ability to produce to a standard product quality. It is determined by:

$$Quality\ rate = \frac{Quality\ product}{Total\ product\ produced}$$

- Overall Equipment Effectiveness – An overall measure that considers uptime, speed, and precision. It is measured as a product of:

$$Overall\ Equipment\ Effectiveness\ (OEE) = availability * process\ rate * quality\ rate$$

(2) Mean Time Between Failures:

$$MTBF = \frac{Number\ of\ operating\ hours}{Number\ of\ breakdowns}$$

- Maintenance breakdown severity:

$$Maintenance\ breakdown\ severity = \frac{Cost\ of\ breakdown\ repair}{Number\ of\ breakdowns}$$

4.10 Application of Decision-Making Support Techniques in PFM Framework

The decision-making analysis procedure is an important activity in PFM. By defining the key strategic manufacturing requirements, assessing the product life cycle and performance of the existing production facilities, it would allow the management to look at the optimised operation management in the production facilities investment of the future. The feasibility analysis of PFM is a typical Multiple Criteria Decision-Making (MCDM) process. The data that are used for the feasibility analysis are collected by the PMS. In the implementation of the developed PFM model several linking tables are developed to link detailed steps and assist the feasibility analysis in PFM. An example linking table, which is used to identify the manufacturing requirements versus different product group life cycle stages, is demonstrated in Table 4.1.

Table 4.1 Corporate Manufacturing Strategy Requirements versus Product Life Cycle Stage Matrix

Corporate strategy requirement		Product Group/Project Life Cycle				
Item	Competitive criteria	Concept	Design and Development	Production (Maturity)	Decline	Rapid decline
1	Cost	●●●●	●●●●	●●●●●	●●●	●●
2	Quality	●●	●●●	●●●●●	●●●	●●
3	Delivery	●	●	●●●●	●●	●
4	Flexibility	●●●●●	●●●●	●●●	●●	●
5	Price	●●●	●●●	●●●●	●●	●
6	Speed	●●●●●	●●●●●	●●●	●●	●
7	Service	●	●●	●●●●	●●●●	●●●

* Symbol "●●●●●" means most significant, " ● " means least significant

The idea of matching product and market evolution with manufacturing-process characteristics is one of the offshoots in the manufacturing strategy decision-making process (Hayes *et al,* 1996). The product-process life cycle suggests that as a product matures, the relative importance of competitive priorities will shift, and these shifts have important implications for manufacturing. For example, in its early stages, a product often competes on the basis of special features or innovative designs. This calls for a production process that is very flexible with respect to market shifts and design changes. Such an operation might employ highly skilled workers, general-purposed tooling, and little automation of the equipment; moreover, it should be located close to R&D and, to reduce the risk of obsolescence, produce small batches.

As the product matures, the market typically evolves toward a small number of high-volume products that compete with each other largely on the basis of price. To this end, factories ought to be highly automated, located in areas where labour or material costs are low, employ less skilled workers, and in order to minimise changeover costs, schedule production around long runs.

Manufacturing strategists have long argued that different production systems exhibit different operating characteristics: some were good at low cost, some at high quality, and some at fast response times. In a PFM framework, management had to decide which is most important and to prioritise sequentially. If there are conflicts amongst different objectives, they have to make tough choices based on a careful analysis of the trade-offs.

More similar matrix and tables are developed and specified in the PFM implementation workbook which is shown in Appendix D.

4.11 Conceptual PFM Implementation Model

Based on the overall PFM process, a further design of the PFM implementation model is developed in Figure 4.12 (Liu *et al*, 1999).

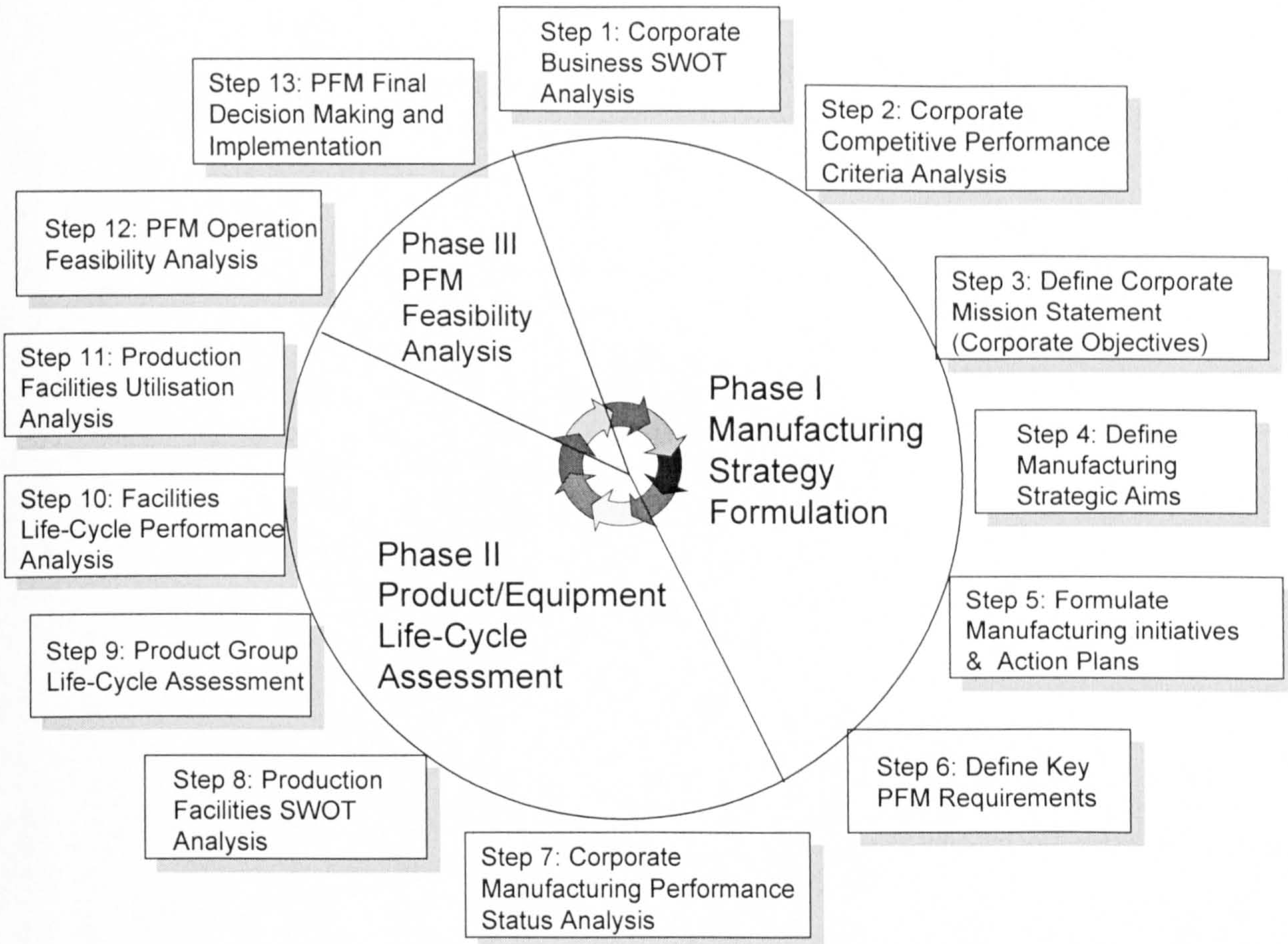


***Figure 4.12 Conceptual Production Facilities Management (PFM) Implementation Model** (Source: Liu et al, 1999)*

The conceptual implementation model includes three phases and 13 major steps and it operates as a circle along with the life cycle of a facility.

4.11.1 Phase I: Manufacturing Strategy Formulation

The purpose of manufacturing strategy formulation is to identify the business competitive focus, corporate objectives, performance measures for the business, manufacturing aims, and manufacturing initiatives. There are six main steps in this phase:

Step 1: Corporate Business SWOT Analysis: To identify the Strengths, Weaknesses, Opportunities, and Threats of the corporate business. SWOT analysis is a cross check from the external (customer) to the internal (company-wide) viewpoint. The result of the SWOT analysis can provide a database for assessing the competitive position of the company in the market and internal diagnosis of the improvement areas of the company itself.

Step 2: Corporate Competitive Performance Criteria Analysis: To find the gap between the customer requirements and the corporate performance so as to define the competitive focus to be improved. The aims of such an analysis is to define the priority of the competitive criteria such as quality, delivery, flexibility, speed, cost. The output of corporate competitive criteria analysis is also used as the basis to define the corporate mission statement in the following step. During the process of corporate competitive criteria analysis, the relative weight of importance of each criterion with respect to each other is also regulated.

Step 3: Define Corporate Mission Statement (Corporate Objectives): The mission statement is derived from the SWOT analysis and it is a statement of corporate purpose. The mission statement is normally described in terms of aforementioned qualitative competitiveness such as quality, delivery, flexibility, cost and combination of the mind of the top management. The key point is the priority of these criteria should be identified so as to generate the priority of the decisions to be made.

Step 4: Define Manufacturing Strategic Aims: The manufacturing aims are expanded from the corporate strategic objectives. The development and determination of the technical approach to accomplish the corporate objectives are defined in this step.

Step 5: Formulate Manufacturing Initiatives and Action Plans: Based on the corporate strategic objectives and manufacturing aims, sequentially developing the initiatives and action plans for the implementation of each item.

Step 6: Define Key PFM Requirements: Capture the strategic objectives and identify the priority of the competitive criteria of the business, in particular focus on the facilities support viewpoint. In this step, all of the Performance Measure (PM) and Performance Indicators (PI) used for the collection of the facilities performance should also be defined. The hierarchy of the PFM PMS of the company is accomplished in this step.

4.11.2 Phase II: Product/Equipment Life Cycle Assessment

The purpose of Production/Equipment Life Cycle Assessment is to identify the product and facilities life cycle stage, and also to identify the production requirements of the facilities utilisation.

Step 7: Corporate Manufacturing Performance Status Analysis: To collect the current operational performance data which includes the historic financial (for cost analysis) and non-financial data (for operational performance analysis) of the corporate level, functional level and operational level.

Step 8*: *Production Facilities SWOT Analysis: To understand the SWOT of current facilities so as to identify the actions that can be taken for improvement.

Step 9: Product Group Life-Cycle Assessment: To identify the weight of importance of each product group through the analysis of the current situation and the possibility of market share promotion. Sequentially define the life cycle of each product.

Step 10: Facilities Life Cycle Stage Analysis: Grouping the key machines and deciding the relative importance of each machine. In this step, the historic operational data of the equipment also has to be collected

Step 11: Production Facilities Utilisation Analysis: To collect and analyse the current utilisation and capacity requirements of production facilities in the future.

4.11.3 Phase III: PFM Feasibility Analysis

The purpose of PFM Feasibility Analysis is to evaluate the performance of production facilities with respect to the strategic requirement and its relationship with the production requirements of the products.

Step 12: PFM Operation Feasibility Analysis: Assessment of the options of maintaining, enhancing or replacing existing operations so as to satisfy the capacity requirement of the production plan. The PFM operation feasibility analysis step is also combined with the application of decision making support technique. The typical application is the Analytic Hierarchy Process (AHP), an example case of the combination being demonstrated in Appendix C.

Step 13: PFM Decision Making and Implementation: Implementing the decisions made through PFM operation feasibility analysis and continuing the monitoring of the performance of the operation. The contents are the list of projects, work packages, timescales, targets, resource allocations and ownership.

4.12 Evaluation Test of the Conceptual PFM Implementation Model

In order to assess the value of the developed PFM conceptual model, a simple evaluation test is executed. Any evaluation should meet the criteria of utility, feasibility, propriety and technical adequacy (Robson, 1993). Utility refers to the overall usefulness of the approach. Feasibility refers to the practicality of using the approach. Propriety emphasises that an evaluation can only be carried out fairly. Given reassurance about utility, feasibility and proper conduct, the evaluation must then be carried out with technical skill and sensitivity. In order to assess the developed PFM framework and implementation process, these criteria are the features of the evaluation process.

The test is implemented with respect to the criteria of evaluation in following steps:

1. Feasibility - Establishment of a "strategically driven" PFM framework which is shown in a Performance Measurement System (PMS) hierarchy.
2. Utility – Validate the coherence of the conceptual model with the specifications that are required for the development of such model. The specifications are discussed in section 4.6 of this chapter.
3. Propriety - Test the conceptual PFM implementation model with example data and combine the assessment process with the application of the AHP (Analytic Hierarchy Process) technique to obtain the result of decision making analysis in PFM.

4.12.1 Application AHP (Analytic Hierarchy Process)

The AHP theory was developed by Saaty in the early 1970s. The benefit of it is that it provides a logical framework to solve the difficulty in determining the priority ranking of alternatives involved in MCDM (Multiple Criteria Decision Making).

The example introduced here is to test the feasibility of the developed PFM conceptual model with the application of the software called "Expert Choice" which was developed by Expert Choice Inc, USA. The development of the "Expert Choice" is based on the theories of AHP and helps in solving the complicated pair-wise calculation issue.

4.12.2 Test Process

The simulation process is compatible with the conceptual PFM implementation model as shown in aforementioned Figure 4.12.

This test process especially demonstrates the process to establish the structure of a PFM performance monitoring system. The test process is implemented as follows:

1. ***Step1: Define the goal, key criteria (PM/PI) and compare the relative "PREFERENCE" with respect to the goal.*** The key point is that the relative "PREFERENCE' of each criterion is decided based on the corporate strategic objectives and business focus (general success areas). Step 1 is accomplished with the establishment of a hierarchical structure of the performance measurement system as shown Figure 4.13. The test result is as shown in Example 1 of Appendix C.

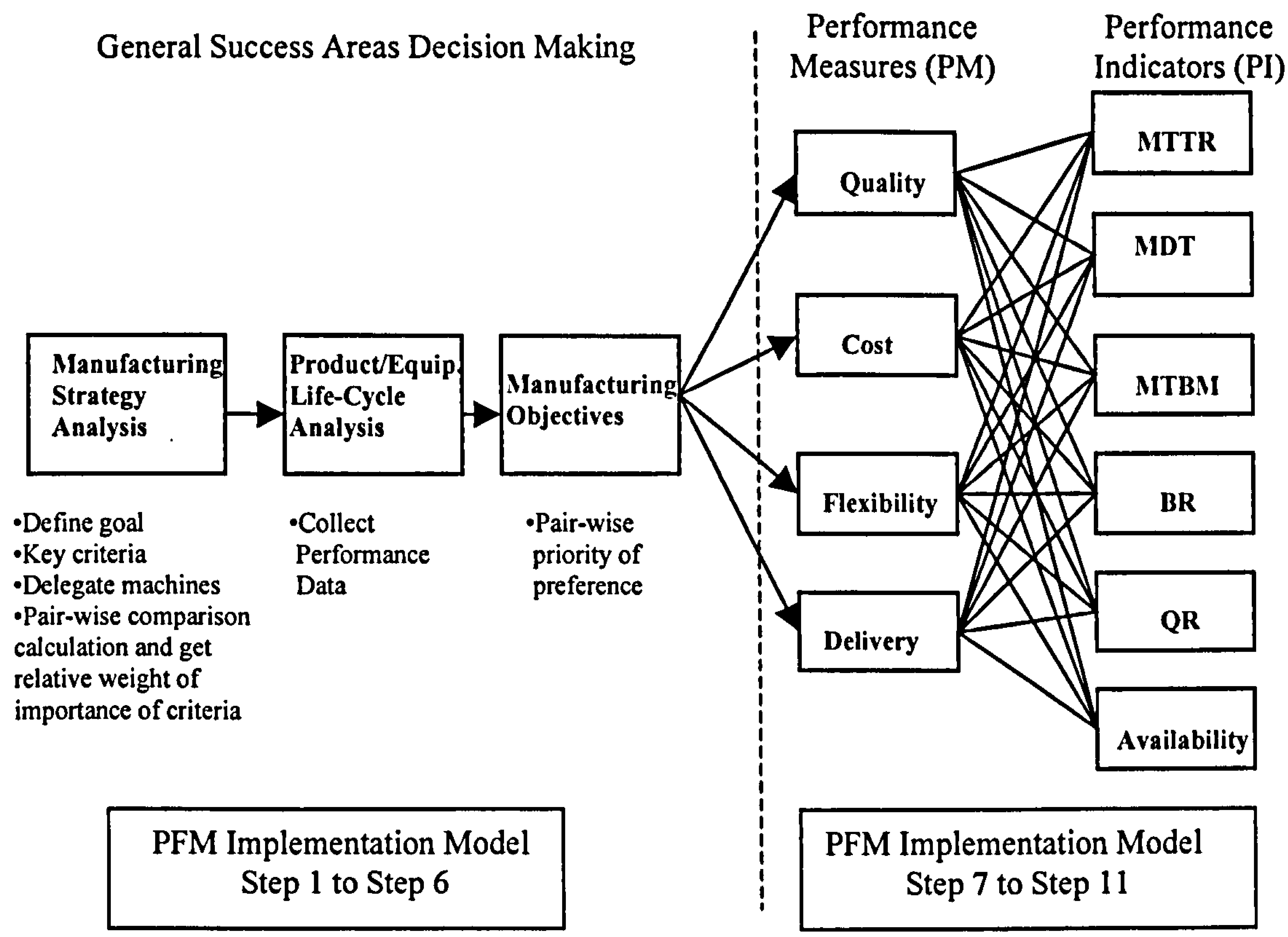


Figure 4.13 Example Hierarchical Structure of Performance Measurement System for Decision-Making Assessment of Replacing Existing Facilities

2. ***Step2: Define the candidate machines involved in decision making assessment.*** The test result is as shown in Example 2 of Appendix C
3. ***Step3: Derive priorities of each criterion with respect to goal.*** The test result is as shown in Example 3 of Appendix C
4. ***Step4: Pair-wise comparison of each delegate machine with respect to each criterion*** The test result is as shown in Example 4 of Appendix C
5. ***Step5: Collecting historic operational data of each machine and pair-wise comparison calculation to get the relative weight of each machine with respect to each criterion (PI).*** The test result is as shown in Example 5 and Example 6 of Appendix C
6. ***Step6: Total pair-wise comparison of each delegate machine with respect to each criterion*** - The larger the total value means the higher possibility the machine will be replaced. The test result is as shown in Example 7 of Appendix C

4.12.3 Findings from the Evaluation Test

This example test brings together the main concepts of the developed strategically driven PMS, the translation of the strategic objectives into the operational requirements, and the application of MCDM technique (introduced as AHP process). This test also proves the feasibility and utility of the developed conceptual PFM model should have considerable benefit to help the decision-making assessment of the PFM in reality.

4.13 Conclusion

Chapter 4 has accomplished some key activities in the development of the PFM framework. These are:

1. Application of the concepts and practices that are adapted from reviewed literature.
2. The specification for the development of a PFM framework has been defined.
3. An overview of the strategically driven PFM process is introduced which specifies the three phases for the implementation work; these being Manufacturing Strategy Formulation, Product/Equipment Group Life Cycle Assessment and PFM Decision-Making Feasibility Analysis.
4. A conceptual PFM implementation circle is developed. The design of this model is based on the defined specifications and it provides a guideline for the development of a detailed implementation workbook.
5. The example test for the feasibility of the conceptual PFM implementation circle is accomplished. The test combines the main concepts of the research and the availability of them in a practical implementation. This test has proved that the conceptual PFM implementation circle should have considerable benefit to help the decision making of the PFM in reality.

The developed process of PFM is structured top-down from the corporate strategy to operation performance monitoring, and feedback of all historic performance data from the bottom of the operational line up to the top management in order to make the proper decision about the fate of these facilities. In order to build up a company-wide consensus, and achieve continuous improvement, there is also a need for a decision making team. The suggested team members should include manufacturing engineers, production operators, maintenance fitters and production managers (Francis, 1992). Successful PMS is implemented through the establishment of a company-wide consensus taking into consideration the following points:

1) Leadership and commitment to measurement and continuous improvement.
2) Full employee involvement and participation in the design, implementation, review and audit of aspects of measurement linked to their progress.
3) Good planning, monitoring and review mechanisms.
4) Good measurement reflects good progress – the two are inseparable
5) Measurement is relative and has to lead to stretch objectives as a result of the benchmarking activity.
6) Good measurement is only concerned with value adding activity – focusing on the customer.
7) Measurement has to focus on 'negative quality' aspects but also has to be used pro-actively for developing a competitive advantage in the marketplace.
8) Measurement in a total quality context is geared for continuous improvement, the control of the processes and activities and not the people.
9) Effectiveness of measurement can be greatly enhanced by reward and recognition systems.

The conceptual PFM implementation circle provides guidelines for the establishment of the implementation process. An implementation workbook is developed based on this conceptual framework which will be described in the following Chapter.

CHAPTER 5

PRODUCTION FACILITIES MANAGEMENT (PFM) IMPLEMENTATION MODEL AND PROCESS DETAILED DESIGN

5.1 Introduction

In chapter 4, a three phases and 13-step conceptual framework of PFM was developed to improve the gaps between theories and practices which were identified in chapter 2. This chapter will further develop the conceptual framework into a more detailed process for pragmatic implementation. The detailed implementation process is related back to the three phases and specifications of the development of the PFM framework in chapter 4. This chapter will first introduce the detailed design of the structure of the PFM framework and then explain the functionality of each section of the implementation framework. For practical implementation, this framework is supported by an associated implementation workbook developed in this research which can be found in Appendix D.

5.2 Detailed Design of the Strategically Driven PFM Implementation Model

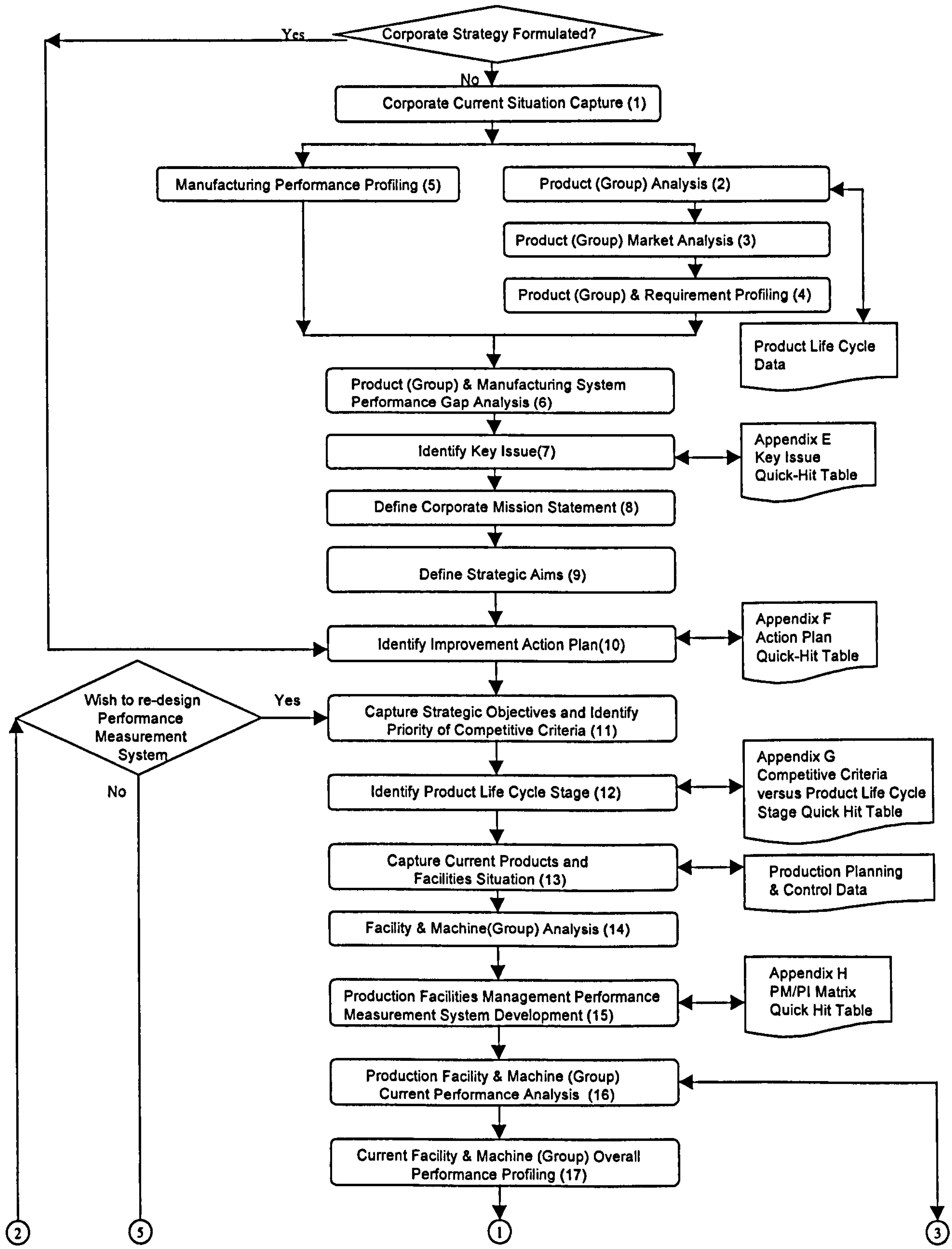
The PFM model serves as a means of linking the manufacturing strategy to the management of production facilities throughout their life cycle. The implementation procedure of the developed process is based on the three phases of the conceptual PFM implementation process. They are manufacturing strategy formulation, product and facility life cycle assessment and PFM improvement plan assessment and implementation (see chapter 4). The development of the detailed implementation process is also based on the specifications of the development of "strategically driven" PFM framework. They are:

1) Coherent with the corporate and operational strategies
2) Adequate measurement of the operation and implementation performance

3) Adequate planning and control of the facilities performance improvement
4) Adequate performance monitoring and assessment technique application
5) Translation and link between business strategic requirements, product life cycle assessment and facilities performance measurement

The three phases and 13-step conceptual implementation process has also been discussed in the 15th ICPR (International Conference on Production Research) which is shown in Appendix M. The content of PFM is a set of decisions in agreed structural and infra-structural areas that are derived from the business strategy.

The detailed implementation process is further designed the conceptual PFM implementation model (as shown in Figure 4.12) into a 26 sections and nine stages detailed implementation framework. The detailed implementation framework is shown in Figure 5.1.


Corporate Strategy Formulated?
Yes
No
Corporate Current Situation Capture (1)
Manufacturing Performance Profiling (5)
Product (Group) Analysis (2)
Product (Group) Market Analysis (3)
Product (Group) & Requirement Profiling (4)
Product Life Cycle Data
Product (Group) & Manufacturing System Performance Gap Analysis (6)
Identify Key Issue(7)
Appendix E Key Issue Quick-Hit Table
Define Corporate Mission Statement (8)
Define Strategic Aims (9)
Identify Improvement Action Plan(10)
Appendix F Action Plan Quick-Hit Table
Wish to re-design Performance Measurement System
Yes
No
Capture Strategic Objectives and Identify Priority of Competitive Criteria (11)
Identify Product Life Cycle Stage (12)
Appendix G Competitive Criteria versus Product Life Cycle Stage Quick Hit Table
Capture Current Products and Facilities Situation (13)
Production Planning & Control Data
Facility & Machine(Group) Analysis (14)
Production Facilities Management Performance Measurement System Development (15)
Appendix H PM/PI Matrix Quick Hit Table
Production Facility & Machine (Group) Current Performance Analysis (16)
Current Facility & Machine (Group) Overall Performance Profiling (17)
2
5
1
3

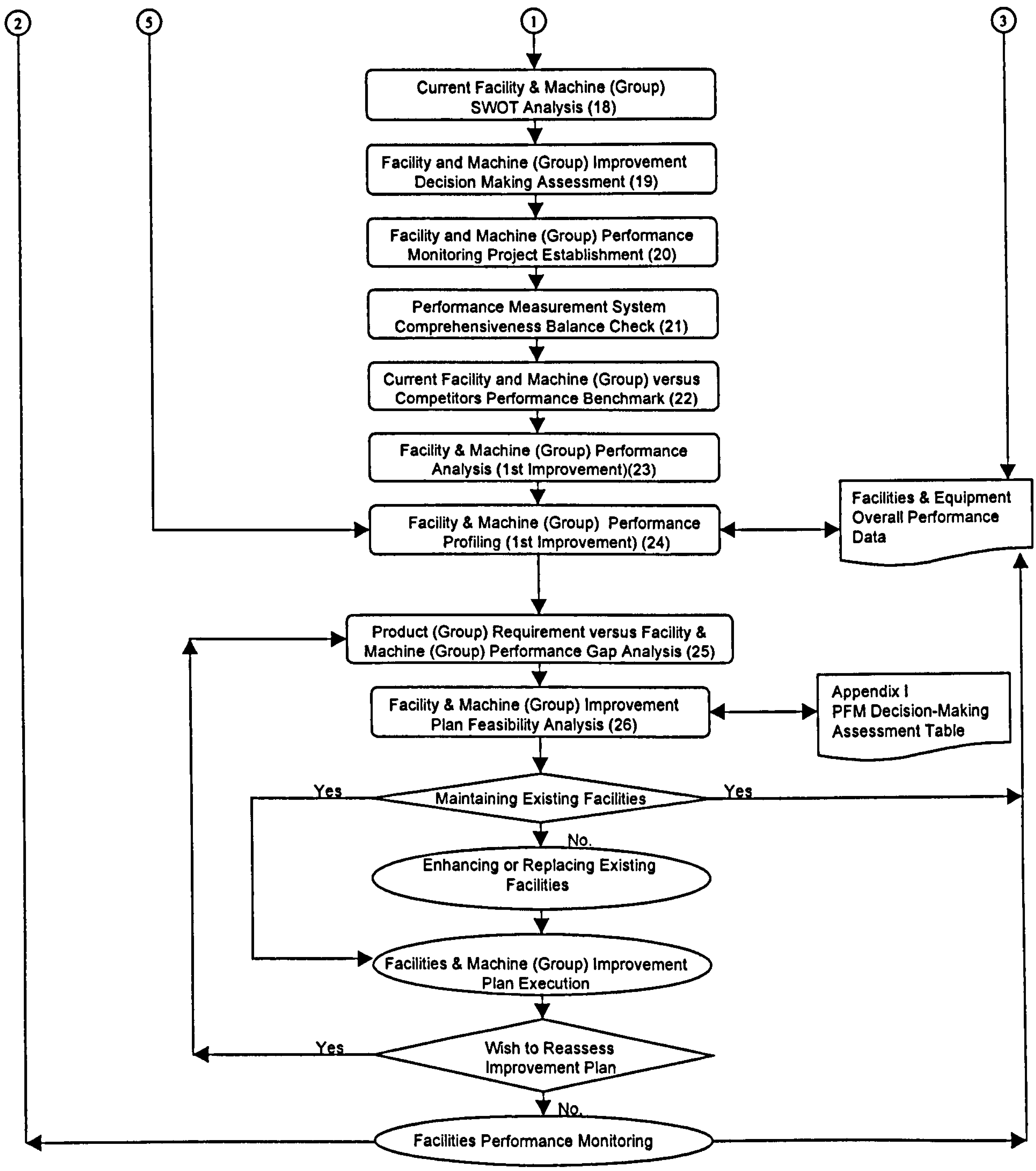


Figure 5.1 Detailed PFM Framework Implementation Process

5.3 Overview of the PFM Framework

In order to present a more detailed description, the implementation process is divided into nine stages and 26 sections for the implementation. Figure 5.2 illustrates the implementation and linkage of the three phases and the implementation stages.

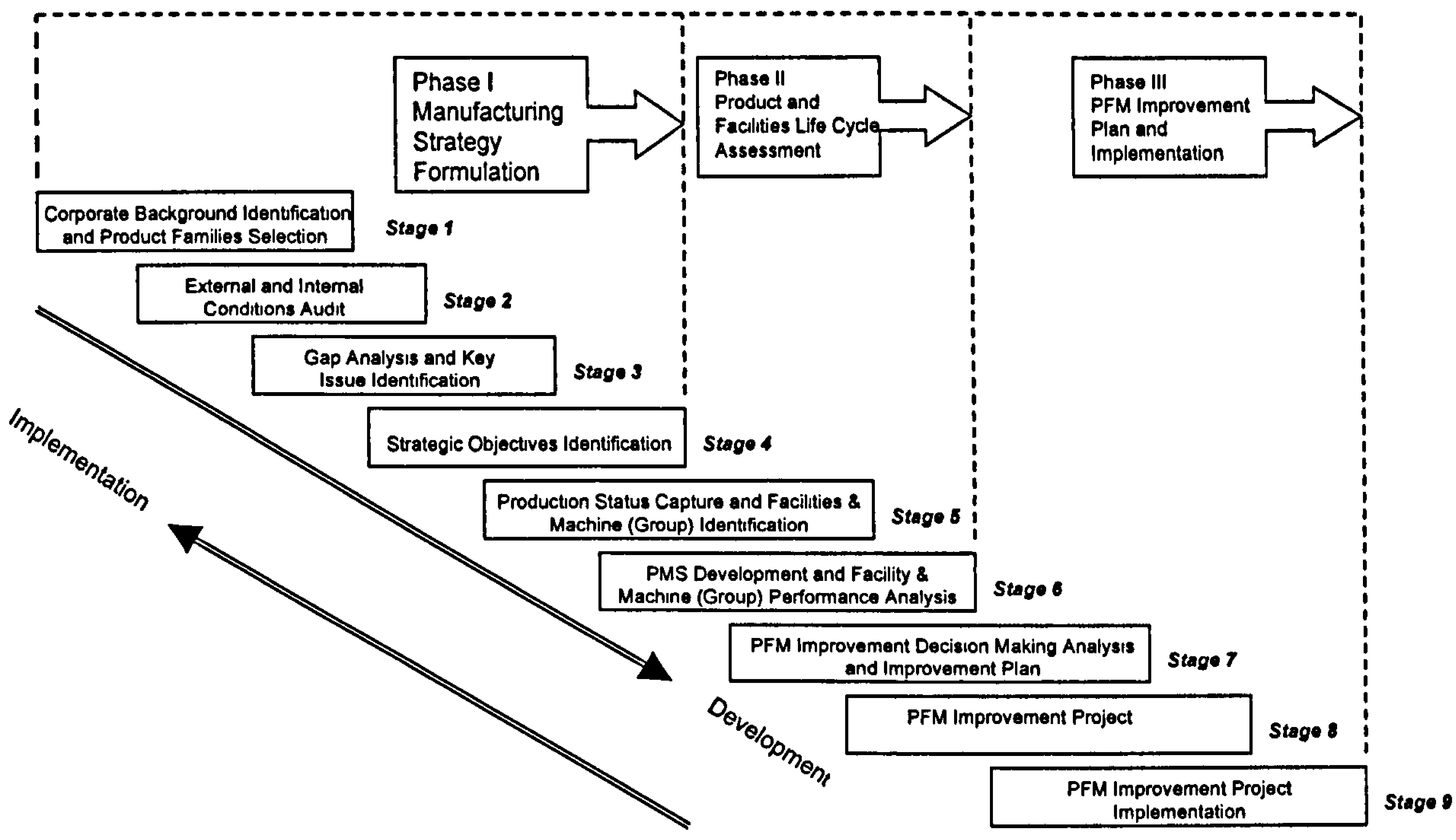


Figure 5.2 PFM Framework and Implementation Linkage

5.3.1 The Nine Stages in PFM Framework Implementation

***Stage 1: Corporate Background Identification and Product Families Selection*:** A top-down manufacturing strategy formulation process requires the manufacturing strategy to be derived from corporate strategy (Skinner, 1969). The aim of the corporate background stage is to understand the current state of the corporation and the role of the manufacturing function of the company. The background study also aims to identify the requirements of the manufacturing system, with respect to the products to be manufactured and assist the definition of the product families. In this stage, products made on the production line may be grouped in terms of their competitive requirements, followed by the formulation of a manufacturing strategy for each group (Neely *et al,* 1996).

Stage 2: External and Internal Conditions Audit: The tasks of this stage is to capture the data related to analysis of the marketing requirements and manufacturing performance of each product (group). The external audit addresses market requirements and competition in order to determine what is required from the products to meet each of the competitive criteria (Hill, 1995). The internal audit considers the manufacturing capability of the company in the context of the existing manufacturing strategy in the competitive criteria.

The internal audit also assesses the state of the current facilities, technology and infrastructure with respect to the intended manufacturing strategy (Hayes *et al,* 1996).

Stage 3: Gap Analysis and Key Issue Identification: Gap analysis is carried out by comparing the results of internal and external audits in order to assess how the manufacturing capabilities will need to change so as to meet the competitive criteria, whilst remaining congruent with the corporate objectives and business strategy (Slack *et al*, 1998). The gap analysis is used to identify the key issues and provide the initiative of the strategic objective.

Stage 4: Strategic Objectives Identification: The tasks of this stage is to translate the shortcomings of the manufacturing system (relative to the competitive strategy) into a set of tangible priorities and objectives (Hull, 1998 and Darlow, 1999). The priorities of the competitive criteria and strategic objectives are used as the agreed targets for the firm to achieve (Neely *et al*, 1996). In order to delivery the performance, each objective should develop a compatible performance measure. This performance measure is used as the driver to assess the performance for the implementation with respect to each competitive criterion.

Stage 5: Production Status Capture and Facility and Machine (Group) Identification: Stage 5 is the first stage of the product and facilities life cycle assessment phase in the implementation process. The task of this stage is to identify the life cycle stage of each product (group). For each different life cycle stage of the product, it will decide a different ability of competitiveness which is shown in terms of the competitive criteria (Leong, 1994). The tasks of this stage also identify the relationship between the products and the facility and machine (group) used to manufacture these products and also to define the groups of these facilities. Different classifications (such as capital investment) of the facilities will influence the weight of importance of the facility and the investment on maintenance cost in decision making afterwards.

Stage 6: PMS Development and Facility & Machine (Group) Performance Analysis: The tasks of this stage is to establish the Performance Measurement System (PMS) to monitor the operational performance of the existing facility and machine (group) (Wireman, 1998). The development of the PMS includes the development of the hierarchical structure of the

PMS, the development of the Performance Measures (PM) and Performance Indicators (PI) for each PM, and the infrastructure between the PM, PI and competitive criteria. The development of an appropriate matrix amongst PM, PI and competitive criteria will help in decision making in PFM.

Stage 7: PFM Improvement Decision Making Analysis and Improvement Plan The tasks of this stage is to analyse the gap in the performance between the strategic requirement and overall performance of the existing facility and machine (group). The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis helps to understand the capability of existing facilities, to support the strategic objectives development of the PFM decision making assessment matrix, and helps to identify the influence of each decision on the performance of existing facilities when the decision is made. The facility and machine (group) improvement decision making assessment is also accomplished within this stage which is implemented with the application of MCDM (Multiple Criteria Decision Making) such as AHP (Analytic Hierarchy Process) (Labib, 1996, 1997, 1998).

Stage 8: PFM Implementation Project: The tasks of this stage is to establish a comprehensive improvement project of existing facilities. The improvement project is implemented with the establishment of the PM and PI and the hierarchical structure of the PMS so as to monitor and assess the performance of improvement (Neely *et al*, 1996). This stage also implements the balance check from the perspectives of financial, customer, internal business, innovation and learning to ensure the comprehensiveness of the improvement plan (Kaplan, 1996). The improvement plan also considers the decision making on the target of PM and PI with benchmarking the performance of competitors and the ability of current facilities so as to make an applicable plan.

Stage 9: PFM Improvement Project Implementation: The tasks of this stage is to realise the improvement plan and gap and analyse the result after it is implemented. This stage also collects the operational data of the facilities and gap analysis with the results between the strategic requirements of the manufacturing system and the achievement of improvement plan. The result of the gap analysis provides the initiative for the next improvement of the production facilities which is based on the concept of continuous improvement of TQM (Total Quality Management) (Logothetis, 1992; and Dahlgarrd, 1998). The next step of the

PFM implementation is then linked to stage 5. The implementation from stage 5 to stage 9 formulates an operational circle. However, the performance of the whole PFM framework also needs to be assessed periodically. If improvement of the PFM framework is required, the assessment should be implemented from stage 1.

5.3.2 Monitoring and Assessment of the PFM Implementation

The assessment of the performance of implementation of PFM is developed under a "top-down" initiative with "strategically driven" concept; whilst it is implemented through a "bottom up" route. The implementation of PFM is a mixture of company wide management information. It is recommended that the performance of this implementation circle should be monitored by a corporate strategy and performance review board. The reviewing board should ideally be composed of:

1) The executors of the business – The personnel with 'strategic concerns'
2) The managers/supervisors – The personnel with 'conflict concerns' in various functions, such as marketing, product design, production engineering, maintenance, logistics, and production planning and control.
3) The shop floor personnel – The personnel with the 'practical operation of the facilities'

The purpose of the review board is to make reasonable decisions and an applicable implementation plan so as to build up a company-wide consensus for the implementation.

5.4 Stage 1: Corporate Background Identification and Product Families Selection

The implementation of stage one includes two sections which are illustrated in Figure 5.3. Each section is associated with an implementation worksheet which is illustrated in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

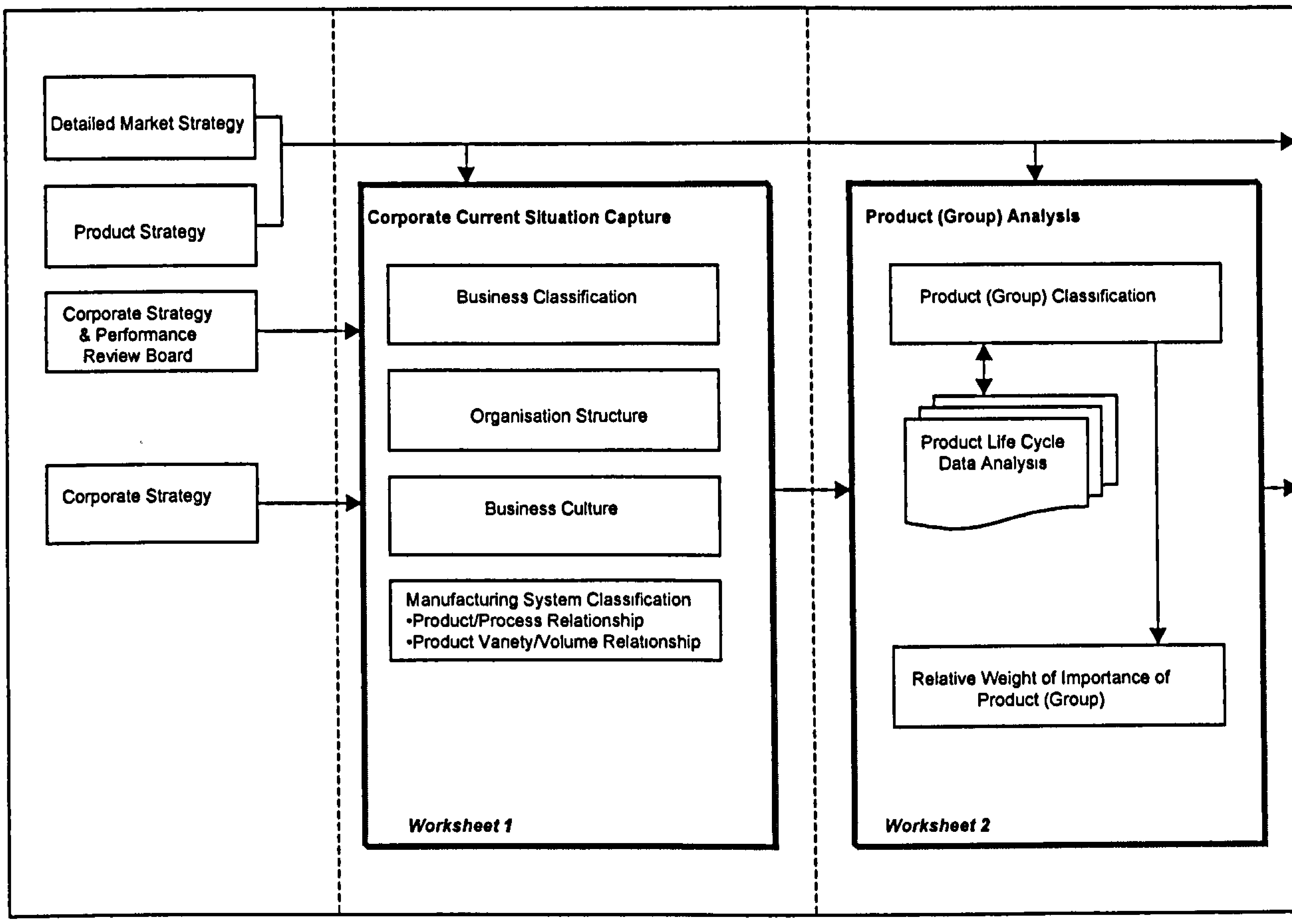


Figure 5.3 Define Corporate Background and Select Product Families Flow Chart

5.4.1 Section 1: Corporate Current Situation Capture

The development of this section is to capture the current corporate situation is to establish the background data of the state of the corporation. The current situation analysis is composed of three key elements: business classification, organisation structure and business culture (Hull, 1998). The output of the section also helps the members of the review board to increase their understanding of the relationship between business and manufacturing so as to meet the strategic concerns. The business can be classified in regard to the business structure, business culture organisation behaviour and operating environment (Hulls, 1998). The manufacturing system can be classified in regard to the product-process matrix (Hill, 1995; Slack, 1998). The typical factors used for the classification include: manufacturing operations process types, such as the project type, jobbing type, batch type and mass production type; the volume and variety of the products, process flexibility and the cost.

The definition of the role of the manufacturing function is the final step in capturing the current corporate situation. It requires the review board to synthesise the corporate situation and conclude the structure of the manufacturing system with respect to the process/product matrix. A different classification of the manufacturing system will influence the decision making of PFM.

5.4.2 Section 2: Product (Group) Analysis

The development of Product (group) analysis is to identify the key products (groups) of the corporation. The final goal is to obtain a relative weight of importance of each product (group) which is accomplished by assessment of the current situation of each product (group) through some agreed performance measures. Typical but not exhaustive measures used for assessment are: variants, volume, sales, % to total sales, % contribution, market share, growth opportunities, degree of innovation, principle processes, materials, approximate profit, costs, order sizes, and market focus (DTI, 1988 and Hull, 1998). The relative importance of each product (group) will sequentially decide the importance of each machine (group) to produce them. The products that have a higher weight of importance are the key products for the business to monitor and the facilities and machine (group) to produce them are the key machines (groups) for the business to support. When thinking about product (group) analysis, it can be useful to apply the concept of 'product life cycle', as this can often clarify the definition of product families and help in establishing subsequent manufacturing implications (DTI, 1988). There are many classifications of the stage of the life cycle of a product. The typical life cycle is divide into market entry, rapid growth, maturity, and decline (DTI, 1988). The measures used for the product (group) analysis should be reviewed periodically by the assessment review board.

5.5 Stage 2: External and Internal Conditions Audit

The implementation of stage two is divided into three sections as shown in Figure 5.4. Each section is associated with a worksheet which is illustrated in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

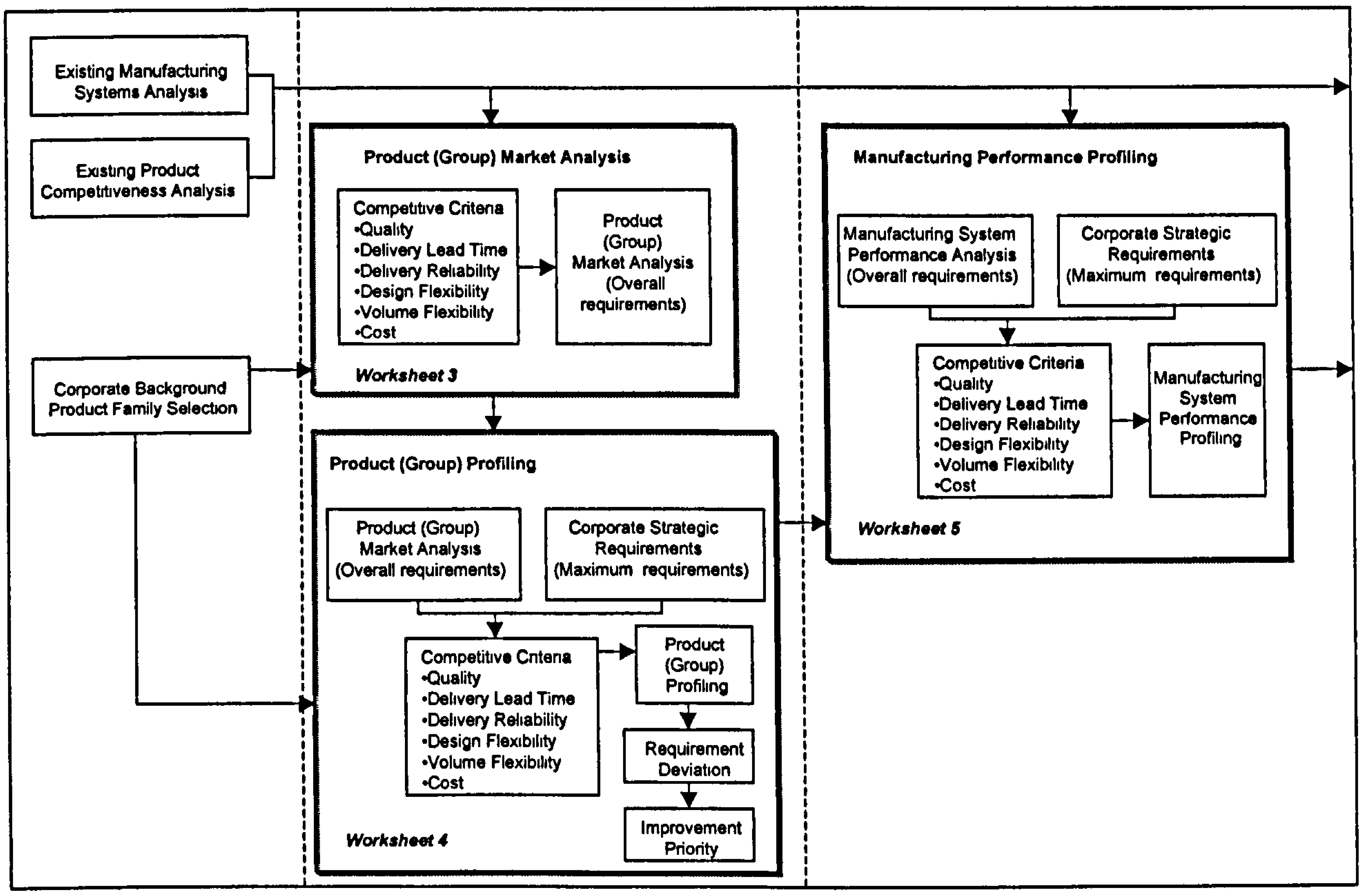


Figure 5.4 Audit External and Internal Conditions Flow Chart

5.5.1 Section 3: Product (Group) Market Analysis

The development of product (group) market analysis is to help the company to obtain a detailed understanding of what is required of each of the products by customers in the chosen market segments. These market requirements will form the basis for all development and investment in the process, technology and infrastructure of the firm. Baker *et al* (1999) stated that there is a strong link between marketing and competitive success.

A number of parameters have been suggested for the assessment of market requirements. The typical measures chosen are (DTI, 1988; Slack *et al*, 1998 and Baker, 1999):

- *Product features*: Adding capability to the product, or choice for the customer
- *Quality:* Conformance to specification, reliability in use

- *Delivery lead time*: Delivering the product within the lead time required by the customer
- *Delivery reliability*: Always delivering on time
- *Design flexibility:* Having the ability to produce products to a customer specification (customisation)
- *Volume flexibility*: Having the ability to supply fluctuating volumes without compromising lead time
- *Price*: Selling at the lowest price

The above parameters are typical but not exhaustive measures and they can be supplemented and customised to meet the specific requirements of the business.

5.5.2 Section 4: Product (Group) Requirement Profiling

The development of product requirement analysis is to assess the performance of each product (group) from the external customer's perspective. This result will provide essential data for understanding the company's performance in the market. This analysis uses the matrix of product (group) with respect to the six typical competitive criteria (quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost) so as to obtain the company's performance in each criterion. There are three kinds of information in the profile.

1. *Overall performance data* – This will provide an average performance of the company with respect to each competitive criterion from the customer's viewpoint. The requirement of customers is shown by their assessment on each product (group).
2. *Maximum performance data* - This is shown by the maximum product requirement with respect to each competitive criterion which will provide the integrated target value in each competitive criterion for the company to approach.
3. *Deviation of maximum requirement and overall requirement with respect to each criterion* – This provides the priority of the improvement with respect to each criterion.

In order to assist in the assessment of the weight of importance of each product (group), a series of Utility Values (UV) and profiles can be constructed (Hull, 1998). The UV described below is a function of the product (group) importance, the importance of the competitive criteria for the individual product (group) and the performance of the individual product (group) with respect to the competitive criteria. Utility Value is used as an analysis tool to assist in the calculation of the relative weight of importance in multiple criteria of each criterion and gain an integrated value with respect to each other (Hull, 1998). The UV is shown as:

$$U = Fn(I(\pi), N(\chi,\pi), \theta(\chi,\pi))$$

Where:

$I = \textit{relative importance derived from manufacturing background}$
$N = \textit{market requirements}$
$\theta = \textit{manufacturing performance}$
$\pi = \textit{product group}$
$\chi = \textit{manufacturing competitive criterion}$

Table 5.1 provides a simple description of how the Utility Value of a product group and competitive criteria is formulated.

***Table 5.1 Product Groups and Competitive Criteria Utility Value Calculation Table** (Source: Hull, 1998)*

Competitive Criteria	Group A	Group B	Group C	Group D	Utility Values
Relative Importance	**Ia**	**Ib**	**Ic**	**Id**	
Quality	**Qa**				**U -Q**
Delivery Lead Time	**DLTa**				**U - DLT**
Delivery Reliability	**DRa**				**U - DR**
Design Flexibility	**DFa**				**U – DF**
Volume Flexibility	**VFa**				**U – VF**
Cost	**Ca**				**U - C**
Product Group Utility Value Profile	**Pa**				**U - total**

The competitive criteria Utility Value *Ux* can be written as:

$$U_x = \sum_{All\ product\ group} (Competitive\ criteria\ x\ relative\ importance)$$

For example, the total Utility Value of Quality criteria

$$Uq = Q_a x I_a + Q_b x I_b + ...\ etc$$

Where:

Uq = *Quality competitive criteria Utility Value*
Q_a = *Quality competitive criteria requirement for product group A*
I_a = *Relative importance for product group A*
P_a = *The profile of product group A*

Such a table can be presented in a polar diagram to get a clearer profile. The advantages of polar diagrams have been proposed by Slack *et al* (1998) and Hull (1998). Figure 5.5 is an example of the polar diagram which illustrates the profile of the product (group) with respect to the competitive criteria.

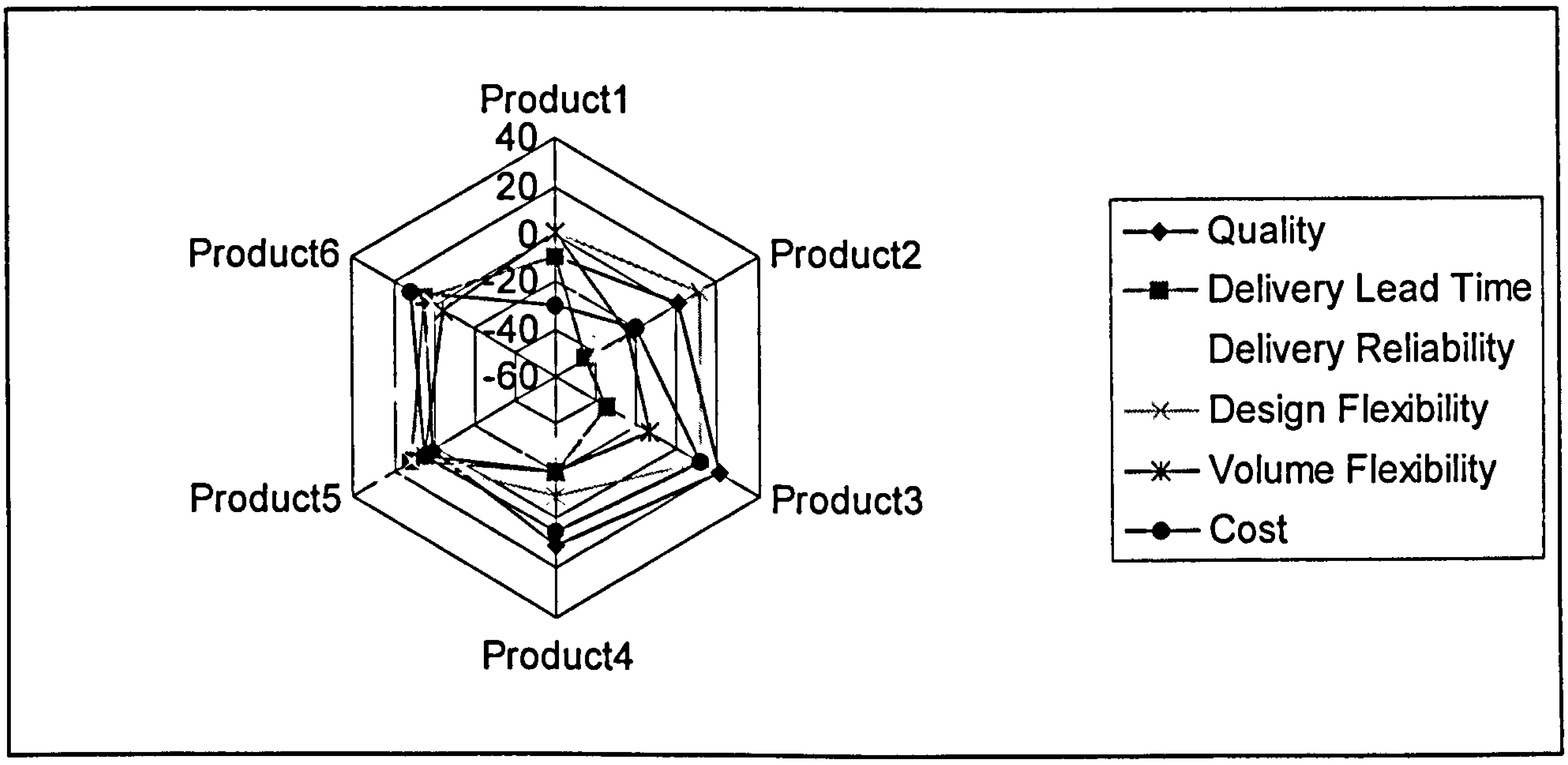


Figure 5.5 Polar Diagram of the Product (Group) and Competitive Criteria

5.5.3 Section 5: Manufacturing Performance Profiling

The development of this section is to analyse the manufacturing performance profiling by assessing the performance of each product (group) from an internal manufacturing perspective. This self-assessment will help in understanding the company's performance in supplying the products to satisfy customer requirements. This analysis uses the same matrix of product (group) with respect to the six typical competitive criteria (quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost) so as to be consistent with the product (group) profiling. There are three kinds of information in the profile.

1. *Overall performance data* – This will provide an average performance of the company with respect to each competitive criterion from the manufacturing viewpoint. The performance of the manufacturing system is shown by the assessment of each product (group).
2. *Maximum performance data* - This is shown by the maximum manufacturing performance with respect to each competitive criterion which will provide the integrated target value in each competitive criterion for manufacturing system to approach.
3. *Deviation of maximum requirement and overall requirement with respect to each criterion* – This provides the priority of improvement with respect to each criterion.

The UV calculation and polar diagram can also be applied in this section so as to assist the analysis.

5.6 Stage 3: Gap Analysis and Key Issue Identification

The implementation of stage three is divided into three sections as illustrated in Figure 5.6. Each section is associated with a worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

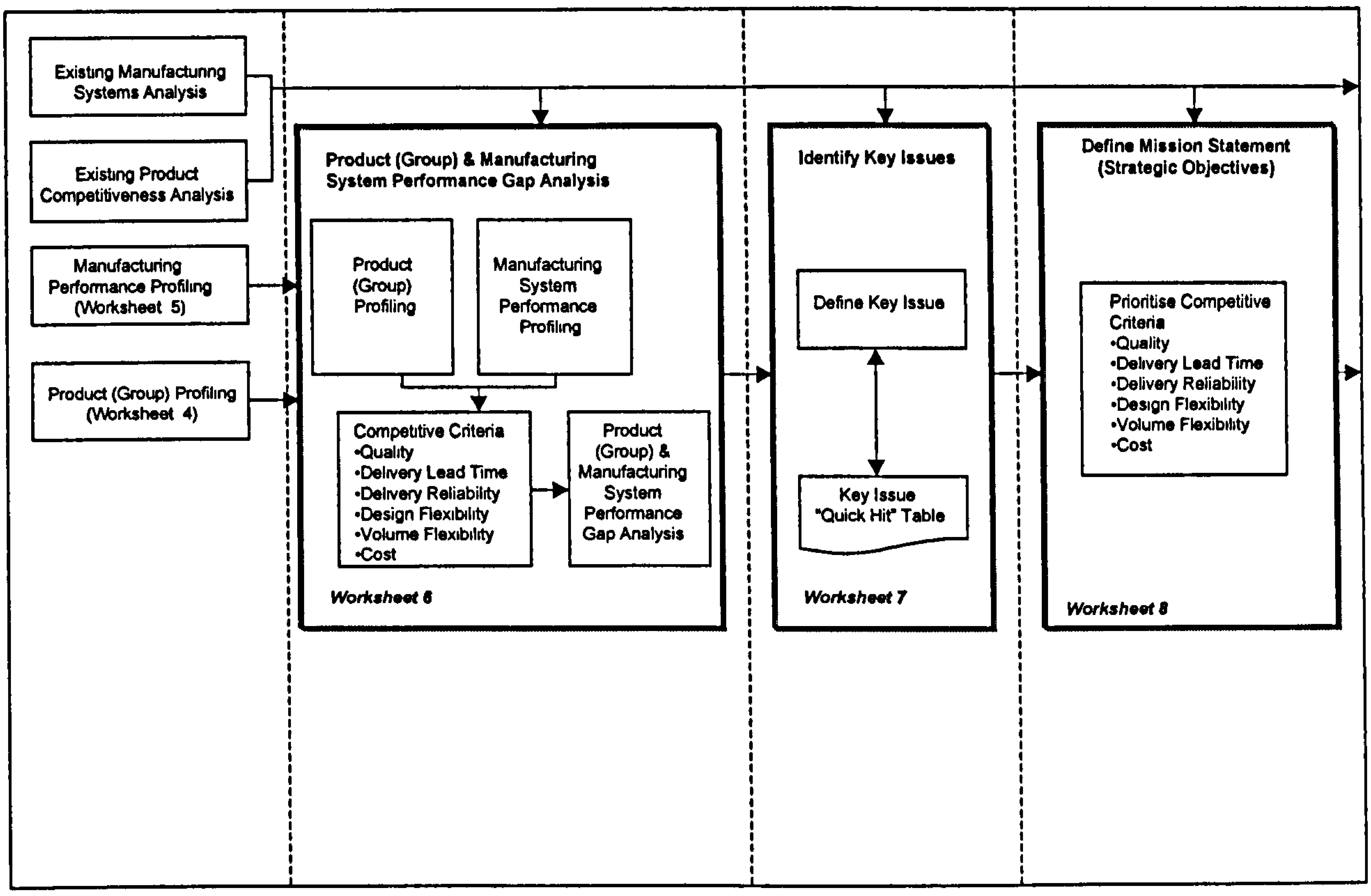


Figure 5.6 Manufacturing Performance and Product Requirement Gap Analysis Flow Chart

5.6.1 Section 6: Product (Group) and Manufacturing System Performance Gap Analysis

The development of product (group) and manufacturing system performance gap analysis is to analyse the deviation between the customer requirements and the performance of the current manufacturing system. The method is to compare the maximum UV value from the manufacturing performance profiling and the maximum UV value from the product (group) requirement profiling with respect to each competitive criterion. The goal is to identify the deviation between external analysis and internal assessment. The deviation will provide the priority of improvement with respect to the competitive criteria. The larger the gap in certain competitive criterion means that more improvement actions will be required to improve the performance. The polar diagram can be used to assist the visual presentation.

5.6.2 Section 7: Identify Key Issues

The development of key issue analysis is to find the reason for the gap between customer requirements and manufacturing system performance. Key issues are events, trends, facts or realities which may have a significant impact on the organisation in general or manufacturing in particular (Greenhalgh, 1991). Many issues only rise to the surface after thorough analysis, in particular an analysis that is inter-disciplinary and multiple-dimensional in nature. The key requirement in implementation is to induct these key issues with respect to the competitive criteria. The typical but not exhaustive issues of the gap are listed in Appendix E. By combining the user's experience and referring to this reference table, the key issues can be highlighted and the strategic aims and improvement action plans can be developed sequentially.

5.6.3 Section 8: Define Corporate Mission Statement (Corporate Objectives):

After establishing the background, manufacturing strategy is formulated by developing a mission statement for the manufacturing unit. The strategy addresses the key competitive issues identified in the corporate mission statement (Voss, 1992). The mission statement is normally described in terms of the aforementioned qualitative competitive criteria such as quality, delivery, flexibility, cost and a combination of the mind of the top management. The key point is that the priority of these criteria should be identified on the basis of the corporate background so as to generate the priority of the decisions to be made. The mission statement formulates the strategic objectives for manufacturing to approach.

5.7 Stage 4: Strategic Requirement Identification

The implementation of stage four is divided into three sections which are illustrated in Figure 5.7. Each section is associated with an implementation worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

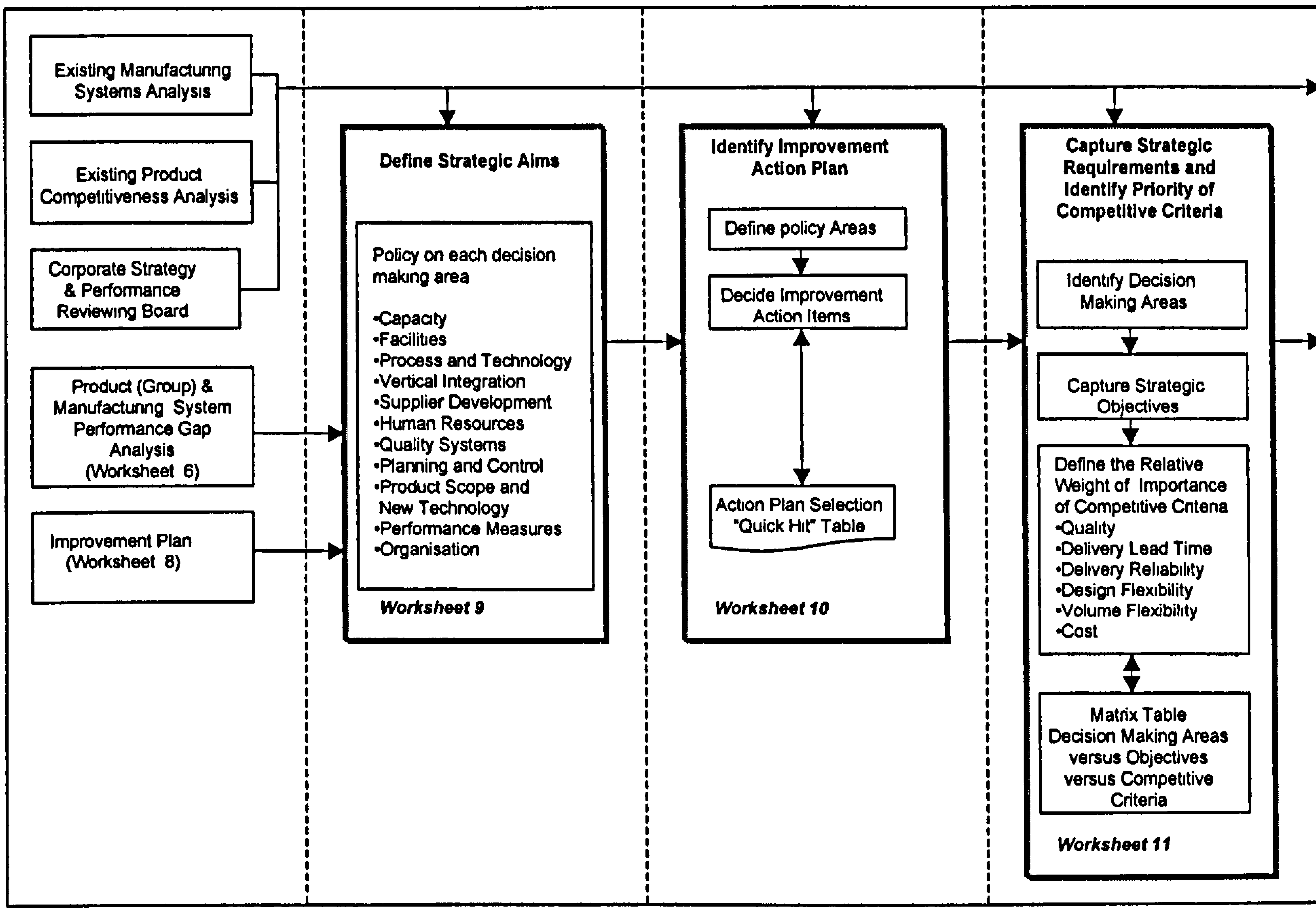


Figure 5.7 Corporate Strategic Requirements Identification Flow Chart

5.7.1 Section 9: Define Strategic Aims

The identification of the strategic aims follows the step of key issue identification. "*A strategic aim is a broad, usually qualitative but result-oriented statement of what must be achieved within the time horizon of the strategy. It provides direction and is a fundamental change in the way we carry out business/manufacturing related activity. In total, strategic aims are a direct response to the key issues and therefore consistent with the function definition and basis for competitive advantage*" (Greenhalgh, 1991).

Although the strategic aims are a direct response to the key issues the response does not have to be on a one for one basis. One particular strategic aim may cover more than one issue. Formulation of the strategic aims is implemented by analysing the current manufacturing policy of the firm and by planning future policy. The manufacturing policy is shown with respect to some decision-making areas. Typically decision-making areas are: capacity, facilities, process and technology, vertical integration, supplier development, human resources, quality systems, planning and control, product scope and new products, performance measures, and organisation (Skinner, 1974; Hayes *et al*, 1984; Platts *et al*, 1988, and Hax *et al*, 1991).

5.7.2 Section 10: Define Improvement Action Plan

The improvement action plan is a set of improvement suggestions based on the strategic aims and key issue identification. The generating process of this plan is to define the required action with respect to each manufacturing policy decision-making area. With respect to the decision-making areas, a number of researchers such as Ward *et al* (1988), De Meyer, (1992) and Hull (1998) recommended the improvement actions that could be taken. A recommended action plan quick hit table is developed as shown in Appendix F. The items developed in Appendix F are typical but not exhaustive ones. The company should develop the proper ones to fit its own situation.

5.7.3 Section 11: Capture Strategic Requirements and Identify Priority of Competitive Criteria

The implementation of the corporate strategy is composed of many trade-offs in different policy decision-making areas. The activities that are implemented in Production Facilities Management (PFM) are more focused on assuring these strategic requirements can be supported and accomplished as a whole. The step of capturing the manufacturing strategic requirements from the manufacturing strategy formulation phase is the first step to link the manufacturing strategy with the following PFM implementation sections. The total performance of the existing manufacturing system can be broken down into the performance of individual facilities and machines (groups). The performance of each facility and machine (group) will influence the competitiveness of the corporation in the end. The key point of this section is to capture the strategic requirements, especially those related to the operation of current facilities. These strategic requirements are derived from the strategic aims with respect to each policy decision-making area.

The performance of the implementation of these strategic requirements in each policy decision-making area will sequentially influence the competitiveness of the company which is determined by six parameters: quality, delivery lead time, delivery reliability, design flexibility, volume flexibility, and cost. The relative weight of importance of these competitive criteria should also be identified in this section.

5.8 Stage 5: Production Status Capture and Facility and Machine (Group) Identification

The implementation of stage five is divided into three sections which is illustrated in Figure 5.8. Each section is associated with an implementation worksheet which is included in PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

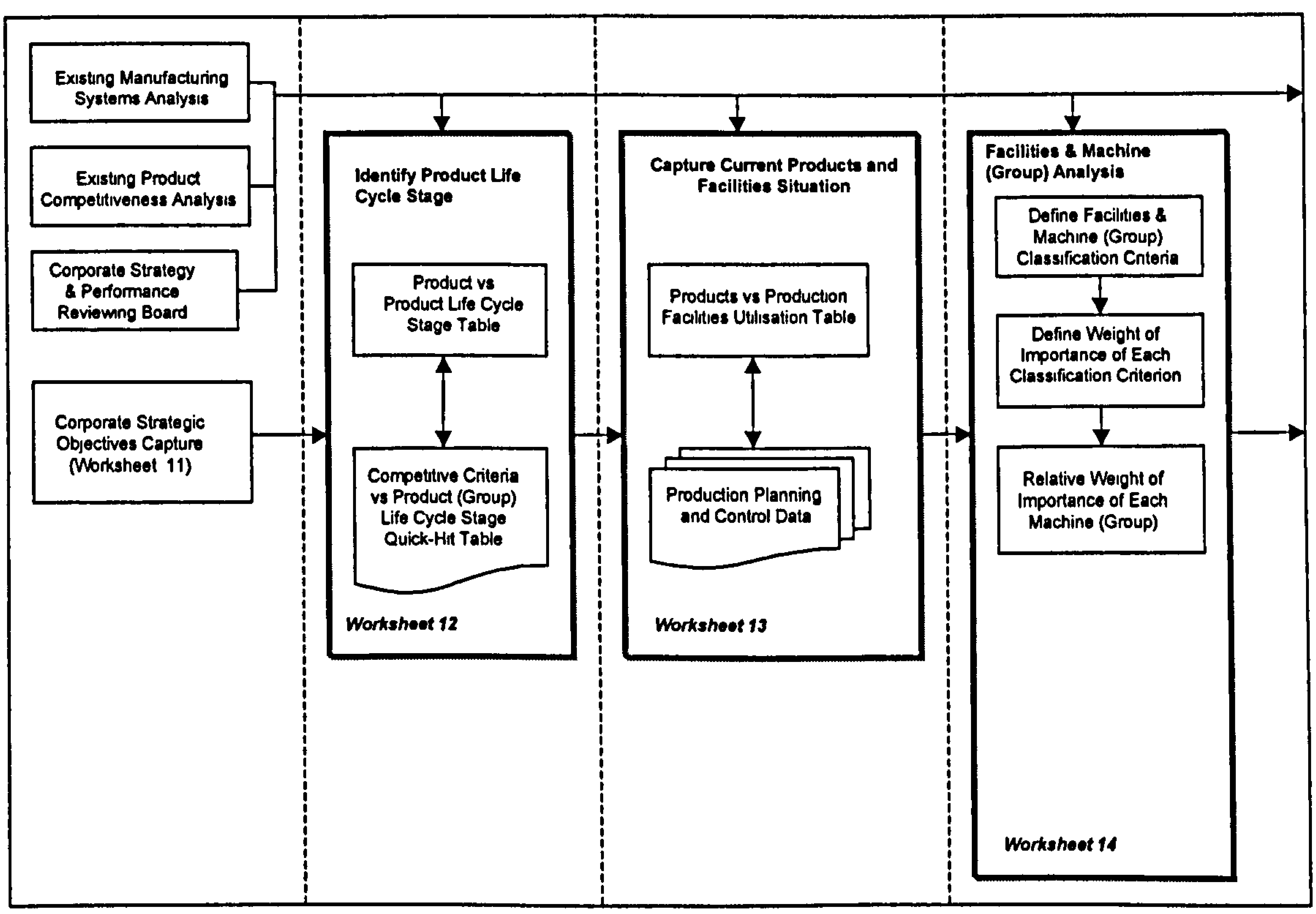


Figure 5.8 Production Status Capture and Facilities and Machine (Group) Identification Flow Chart

5.8.1 Section 12: Identify Product Life Cycle Stage

The function of the production facility is to transfer raw materials into profitable products. Every product has its own product life cycle stage. The demand of the customer (market) will decide the life cycle stage of the product and sequentially influence the management of these production facilities or machines (groups). A typical life cycle of a product (group) is divided into five stages, which are concept, design and development, production, decline, and rapid decline (Baker *et al*, 1999 and Stonebraker, 1994). Each different stage of a product's life cycle decides a different weight of importance of the product (group). The identification of the product's life cycle stage is based on the data analysis from the product (group) analysis in section two.

The identification of the product's life cycle stage will sequentially influence the weight of importance of each competitive criterion, i.e. quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost. To find a balance amongst these criteria and sequentially decide the priority of them is a critical step in PFM. Each company should make its own choice of their priorities so as to match the corporate background. An agreed quick hit table of the weight of importance of the competitive criterion with respect to the life cycle stage should be determined by the review board. Table 5.2 shows an example matrix table of the relationship between the competitive criteria and the product life cycle stage,. A more detailed descroption of the application of this table is also shown in Appendix G. The purpose of this quick hit table is to identify the weight of importance of each competitive criterion in each different stage of the product life cycle.

Table 5.2 Example Competitive Criteria versus Product Life Cycle Matrix Quick Hit Table

Manufacturing strategy requirement		Product (Group) Life Cycle Stage				
Item	Competitive criteria	Concept	Design and Development	Production	Decline	Rapid decline
1	Cost / price	•	••	•••	••••	•••••
2	Quality	•••••	•••••	•••••	••••	•••
3	Delivery Reliability	•	•••	••••	•••	•••
4	Delivery Lead Time	•••••	•••••	•••	••	•
5	Design Flexibility	•••••	••••	•••	••	•
6	Volume Flexibility	•••••	••••	•••	••	•
The symbol of "•••••" means the most important, the symbol of " • " means the least important						

5.8.2 Section 13: Capture Current Products and Facilities Situation

The development of this section is to analyse the status of production and utilisation of the machine (group) to produce these products. The data to be analysed are derived from the production planning and control databank. The goal is to identify the key product (group) and key machine (group) so as to predict the working load of each machine with respect to each product in the future. Each machine (group) to produce the key products is the key machine (group) to the manufacturing function of the company. A number of parameters can be used to analyse the relationship between the current product and facilities situation. Typical parameters are: production years at present, expected production years, total number of products required, unit working hours on each machine (group), and total working hours required on each machine (group). However, every company should define their own parameters for the production status and future requirement analysis.

5.8.3 Section 14: Facilities and Machine (Group) Analysis

The development of this section is to group the key facility and machines (groups) and decide the relative importance of them. The facilities and machine (group) analysis provides a tool to aid the grouping of existing facilities and machines (groups). Typical but not exhaustive parameters in application are listed in Table 5.3. By the application of Utility Value calculation, the relative importance of each machine (group) can be decided. The relative importance of each machine (group) will sequentially influence the decision to make in maintaining, enhancing or replacing them in the end.

Table 5.3 Facilities and Machine (Group) Analysis Table

Item	Degree	Weight of Importance of Different Degree	Mach1	Mach2	Mach3	Mach...
Original Purchasing Price						
Process Type						
Precision Specification						
Throughput Time						
Productivity						
Space Utilisation						
Calibration Requirement						
Expected Service Period						
Maintainability						
Operational Capacity						
Utility Consumption						
Breakdown Frequency						
Quality Rate						
Availability						
Annual Maintenance Cost						
Total Maintenance Cost						
Functional Replacement Ability						
Others						
Relative Importance						

5.9 Stage 6: PMS Development and Facilities and Machine (Group) Performance Analysis

The implementation of stage six is divided into three sections which are illustrated in Figure 5.9. Each section is associated with an implementation worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

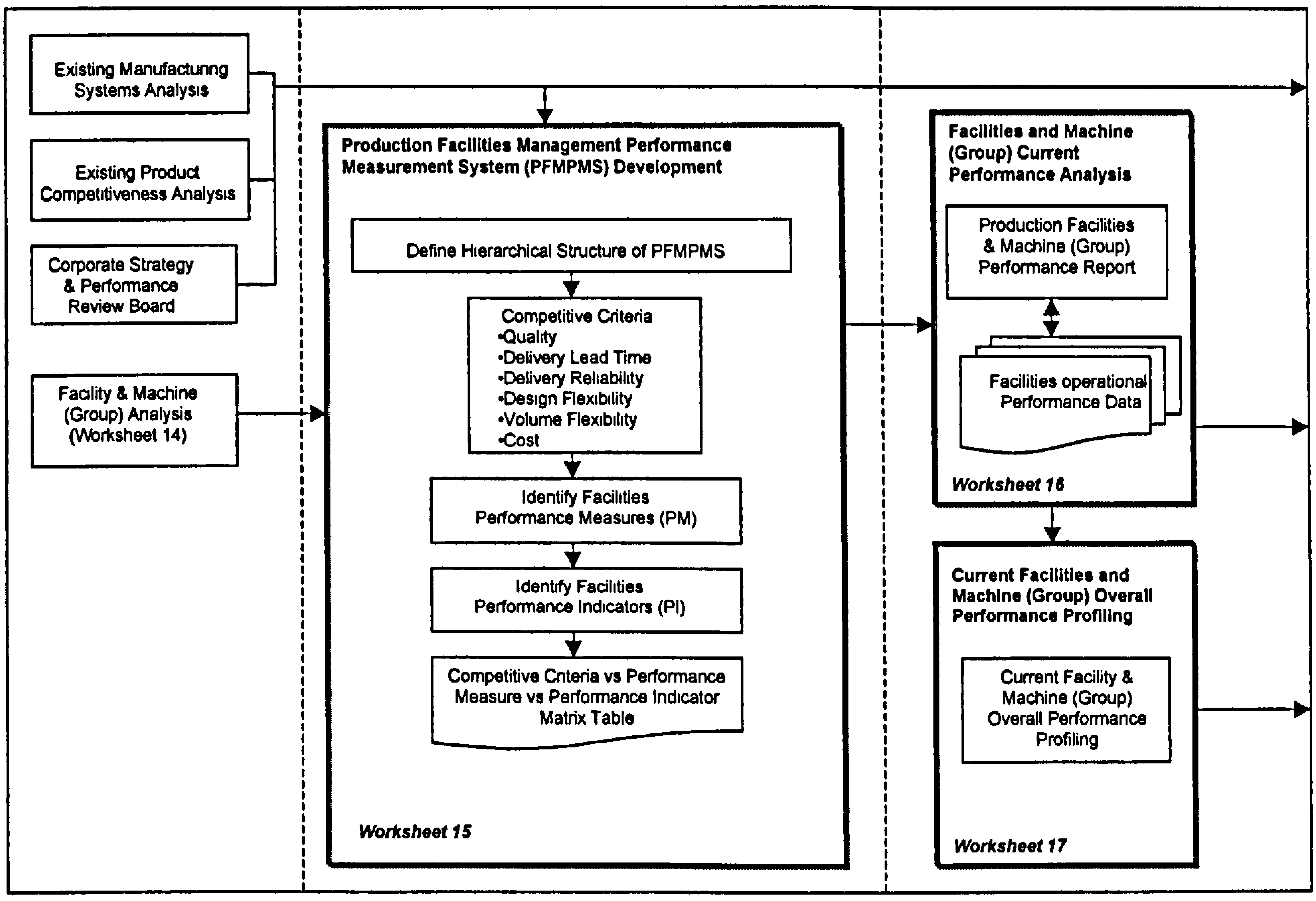


Figure 5.9 Performance Measurement System Development and Facilities and Machine (Group) Performance Analysis Flow Chart

5.9.1 Section 15: Production Facilities Management Performance Measurement system (PFMPMS) Development

The objective of this section is to develop a performance measurement system for the identification of the hierarchy of the competitive criteria, Performance Measures (PM) and Performance indicators (PI). Each company can make its own choice of these competitive criteria, PM and PI, with respect to the type of industry, production methods, manufacturing process, and technology. A hierarchical structure of the PFM PMS is formulated as shown in Figure 5.10.

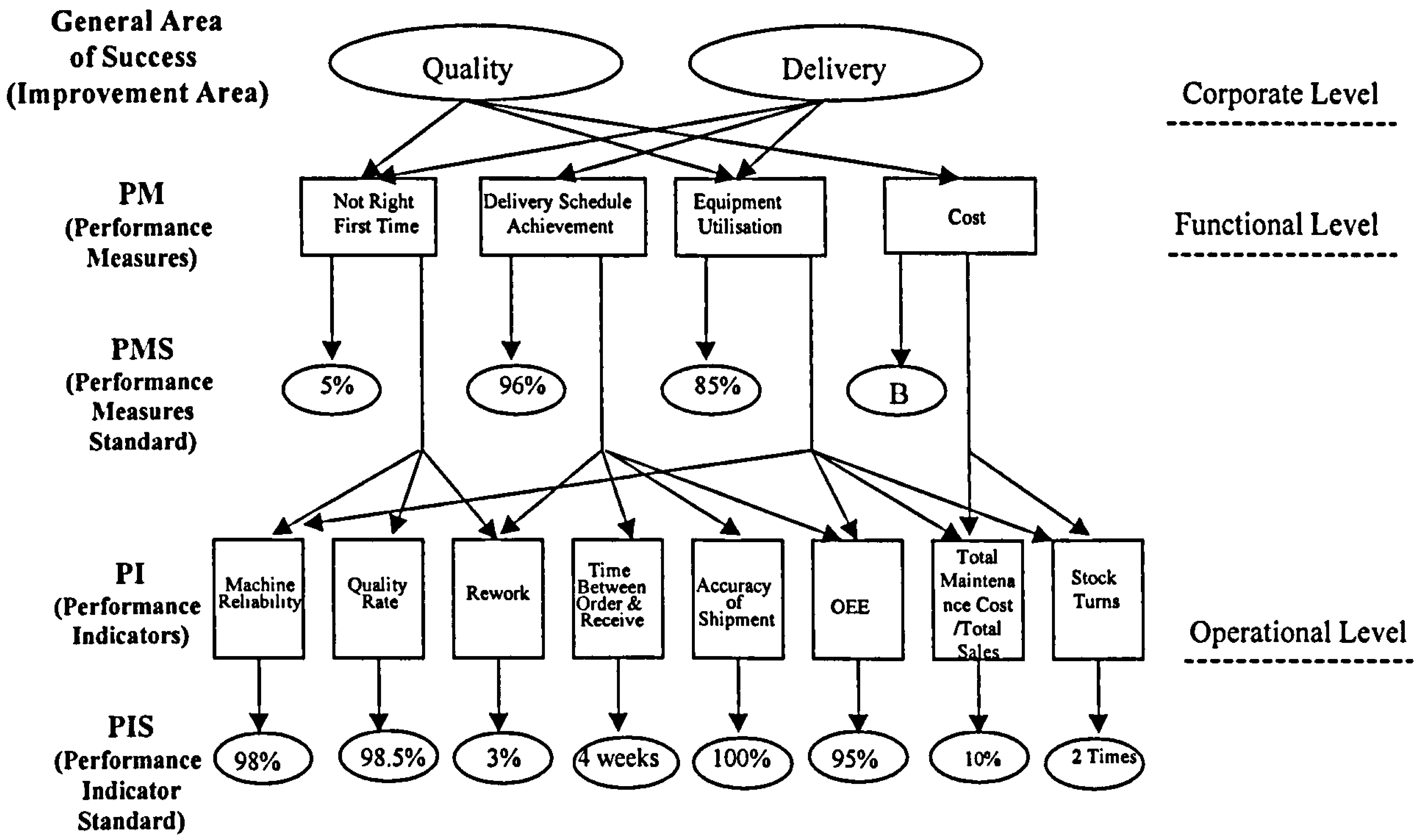


Figure 5.10 Example Performance Measurement System Tree in PFM
(Source: Modified from Ghalayini, 1997)

This diagram shows the hierarchy of the different activities within the organisation and supports the notion that these activities should be measured, controlled, and improved in order to achieve the stated strategic objectives (e.g. reliable delivery). The performance measurement system tree in PFM consists of the performance measurement requirements in three levels of the organisation, these being the corporate level, functional level and operational level. Figure 5.10 also shows how the performance measures and the performance indicators for different areas of success are related. Identifying the interactions between the different performance measures and performance indicators helps the company determine how to improve the performance of several areas of success by focusing on one performance indicator. The hierarchy of the system also specifies the methodology to translate the strategic objectives (general area of success) into the requirements of implementation in the operational level (performance measures and performance indicators).

A typical matrix table used to illustrate the relationship between these competitive criteria, PM and PI, is shown in Table 5.4.

Table 5.4 Competitive Criteria, Performance Measures and Performance Indicators Matrix Table

Criteria						Performance	Indicators					
Q	DLT	DR	DF	VF	C/P	Measures	Mean Corrective Time	Breakdown Frequency	Set-up Times	MTBM	MTBR	Others
						Maintainability						
						Reliability						
						Availability						
						Labour						
						Supportability						
						Skill						
						Tooling						
						Calibration						
						Capacity						
						Construction						
						Documentation						
						Dimension						
						Space Utilisation						
						Productivity						
						Lay-out						
						Location						
						Cost Factors						
						Safety						
						Quality Factors						
						Delivery Schedule Achievement						
						Others						

In this research, a recommended PM/PI convertible matrix is developed in the PFM implementation workbook which is shown in Appendix H. The structure of the PFM PMS should be periodically reviewed by the strategy review board so as to keep up with the changing environment.

5.9.2 Section 16: Facilities and Machine (Group) Current Performance Analysis

The development of this section is to record the operational data of each machine (group). The key point of the implementation is to determine the appropriate parameters to monitor the performance of facilities and machines (groups). A number of parameters are recommended for the purposes of operational data collection and analysis (Wireman, 1998). Even though it is recommended to be as comprehensive as possible, it is not necessary to use all of them in decision-making regarding maintaining, enhancing or replacing these machines. These data also provide the background data for the performance gap analysis. Most of the operational performance parameters are derived from a number of researchers of TPM (Gotoh, 1991, and Sekine, 1998), RCM (Kelly, 1997; and Smith, 1993), ILS and CALS (Blanchard, 1992, Knezevic, 1993 and 1997). The data to be recorded should be chosen through the commitment of management, and the functional and operational levels within the company. Table 5.5 shows some of the typical parameters developed.

Table 5.5 Facilities and Machine (Group) Operational Performance Data Analysis Table

Performance Measures (PM)	Performance Indicators (PI)	Unit	Mach1	Mach2	Mach3	Mach ...
Maintainability	Mean Time To Repair (MTTR)					
	Mean Corrective Time					
	Mean PrevenATtive Maintenance Time					
	Mean Active Maintenance Time					
	Mean Time Between Replacement (MTBR)					
	Mean Time Between Maintenance (MTBM)					
	Mean Logistics Delay Time (LDT)					
	Mean Administrative Delay Time (ADT)					
	Mean Maintenance Down Time (MDT)					
	Replacement Frequency (RF)					
Reliability	Breakdown Frequency (BR)					
	Failure Rate (FR)					
	Total Operating Hours					
	Mean Time Between Failure (MTBF)					

Performance Measures (PM)	Performance Indicators (PI)	Unit	Mach1	Mach2	Mach3	Mach …
Cost Factors	Maintenance Cost per System Operating Hour					
	Cost per Maintenance Action					
	Total Maintenance Cost					
	Total Maintenance Cost / Total Life Cycle Cost					
	Total Maintenance Man Hours					
Quality Factors	Quality Rate (QR)					
	Quality Product Numbers					
	Total Products Produced					
Flexibility Factors	Availability (Schedule Time – All Unplanned Time) / Schedule Time					
	Process Rate (Ideal Cycle Time / Actual Cycle Time) = Efficiency Ratio					
	Actual Cycle Time = Total Working Hours + Total Maintenance Man Hours (Includes LDT and ADT)					
	Overall Equipment Effectiveness					

5.9.3 Section 17: Current Facilities and Machine (Group) Overall Performance Profiling

The tasks of this section is to obtain the overall performance profiling of the key machine (group) with respect to each competitive criterion. The overall performance of each machine (group) can be determined by six criteria: quality, delivery reliability, delivery lead time, design flexibility, volume flexibility, and cost. The performance of each criterion is an accumulated result from the performance of the sub-ordinary PM and PI. The relationship between these competitive criteria, PM and PI, is defined by the hierarchy of PFM PMS. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirement. The implementation process is the same as the analysis of manufacturing system performance profiling in section five. The UV value calculation and polar diagram can also be used for analysis in this section.

5.10 Stage 7: Facilities SWOT (Strengths Weaknesses Opportunities and Threats) Analysis and Improvement Decisions Assessment

The implementation of stage seven is divided into two sections which are illustrated in Figure 5.11. Each section is associated with an implementation worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

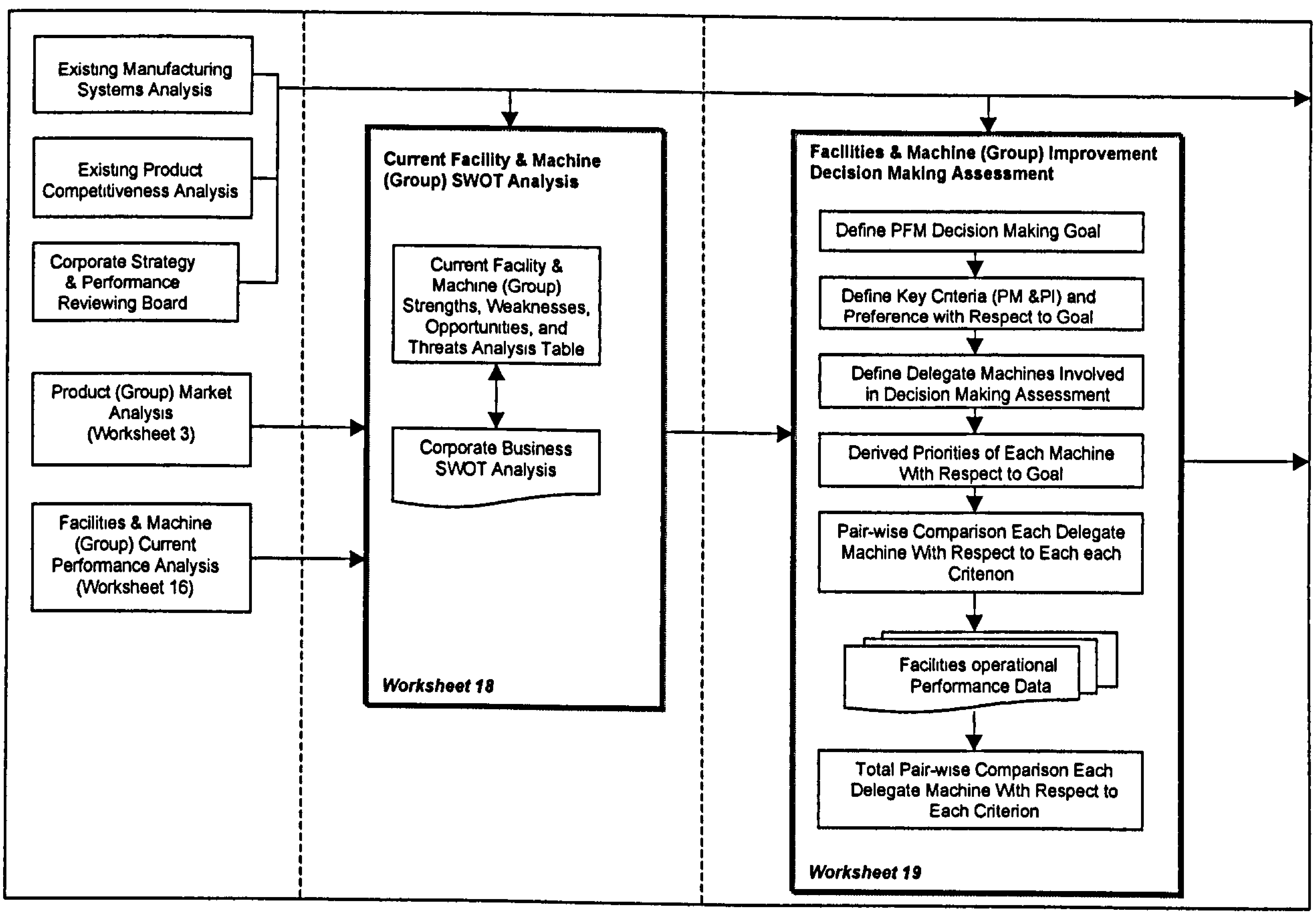


Figure 5.11 Facilities SWOT Analysis and Improvement Decisions Assessment Flow Chart

5.10.1 Section 18: Current Facilities and Machine (Group) SWOT Analysis

The development of this section is to analyse the Strengths, Weaknesses, Opportunities and Threats (SWOT) of the current facility and machine (group).

- Strength: Those activities, systems, technologies, procedures and so on which the company does uniquely well.

- Weakness: Those items (as strength) which the company does not do at an acceptable standard.
- Threats: Those activities, (systems etc.) or events or potential events which might prevent the company reaching the corporate strategic objectives.
- Opportunities: Those activities, events or potential events where the company might additionally exploit the competitiveness in the market.

A typical SWOT analysis process has been discussed by several researchers (Johnson et al, 1993 and Hull, 1998) as illustrated in chapter two. SWOT analysis provides a mechanism for systematically thinking through the extent to which the organisation can cope with its environment. The key point in the analysis requires an understanding of both the environment and the resource capabilities of the company.

5.10.2 Section19: Facilities and Machine (Group) Improvement Decision-Making Assessment

The section describes the analysis needed to consider the possibility of replacement of each facility and machine (group) with respect to their current overall performance. This assessment is accomplished with the application of AHP (Analytic Hierarchy Process). The hierarchy of the decision-making is based on the hierarchical structure of the PFM PMS. The background data for the assessment comes from the current facility and machine (group) performance analysis that is derived from section sixteen. The steps of the assessment are outlined as follows:

Step 1: Define PFM decision-making goal – The goal is usually defined as 'replacing current machine'.

Step 2: Define key criteria (PM & PI) and preference with respect to goal – This is accomplished with the definition of the hierarchical structure of the PFM PMS.

Step 3: Define delegate machines involved in decision-making assessment

Step 4: Derived priorities of each machine with respect to goal – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

Step 5: Pair-wise comparison each delegate machinery with respect to each criterion – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

Step 6: Total pair-wise comparison each delegate machine with respect to each criterion – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

5.11 Stage 8: PFM Implementation Project Feasibility Analysis

The implementation of stage eight is divided into three sections which are illustrated in Figure 5.12. Each section is associated with an implementation worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

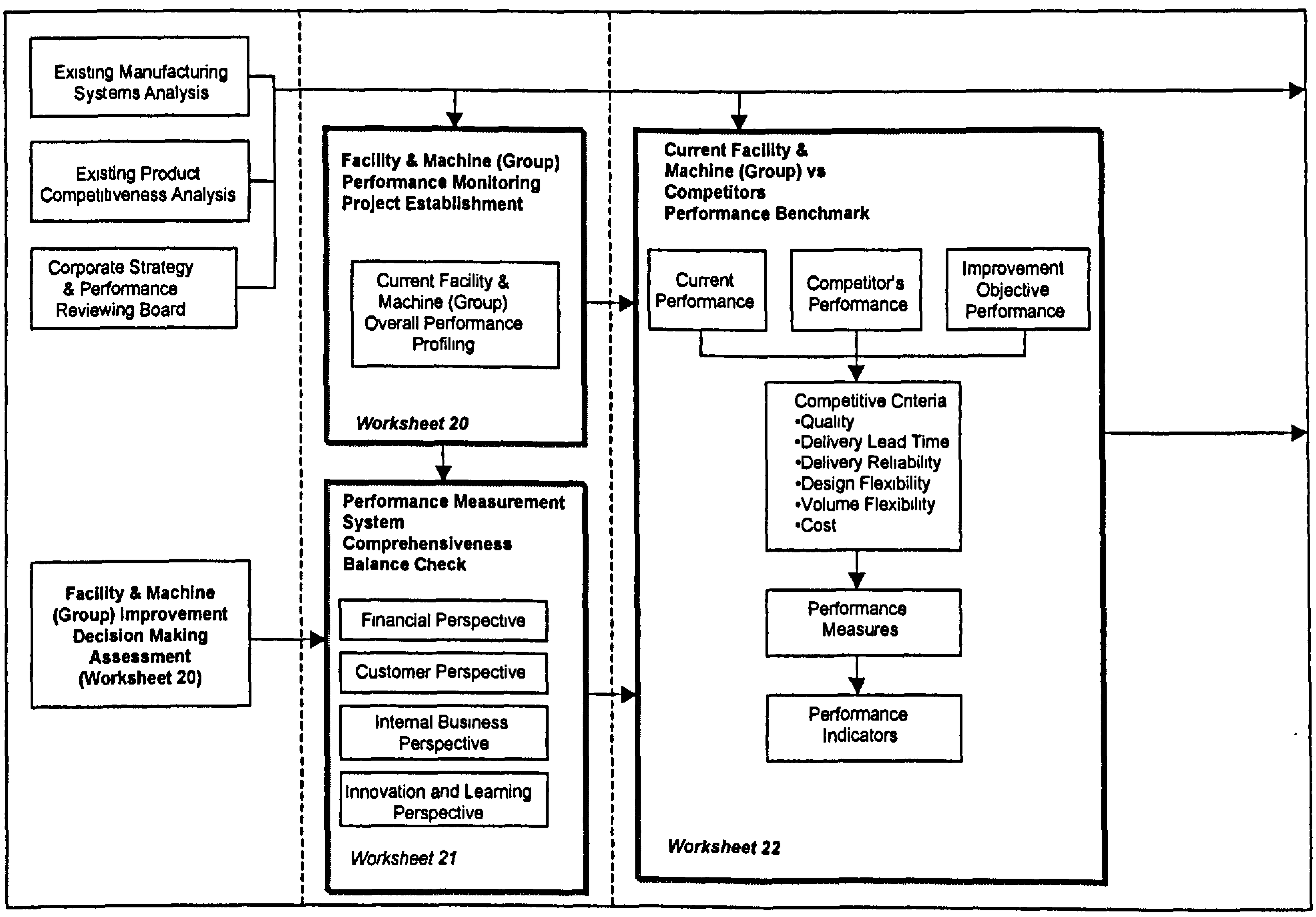


Figure 5.12 PFM improvement Project Comprehensiveness Check Flow Chart

5.11.1 Section 20: Facility and Machine (Group) Performance Monitoring Project Establishment

The development of this section is to establish a project to monitor the performance of each facility and machine (group). The monitoring project is a follow-up of the improvement plan. The key elements in the monitoring project are: the PM and PI, the objective of each PM and PI, the current achievement in each PM and PI, the time span of the improvement plan, responsible party/personnel, and assessment period. The monitoring project is very important because it clarifies the target to be achieved and provides an opportunity to correct the deviation. Every piece of operational performance data with respect to each PM and PI should be monitored, recorded and analysed periodically.

5.11.2 Section 21: Performance Measurement System Comprehensiveness Balance Check

The development of this section is to check the comprehensiveness of the improvement action plan and the availability of each PM and PI. The recommended method is the application of the concept of the Balanced Scorecard developed by Kaplan (1992). The improvement project is checked from four perspectives:

1. *Financial perspective*- How do we look to the shareholder?
2. *Customer perspective* – How do customers see us?
3. *Internal business perspective* – What must we excel at?
4. *Innovation and learning perspective* – Can we continue improvement and increase value?

The contents to be checked include the goal, measures, relation between competitive criteria and strategic objectives with respective to these four perspectives.

5.11.3 Section 22: Current Facility and Machine (Group) and Competitors' Performance Benchmark

The development of this section is to cross check the performance of PFM from the internal (company) and external viewpoint to assure the comprehensiveness of the improvement project. The method is to compare the company's current performance and target to be improved with the competitor's current achievement in each competitive criterion. There are three initiatives in this section, they are:

1. To try to predict their future strategies.
2. To assess accurately competitor's probable reactions to internal strategic moves.
3. To estimate their ability to match the own company in the quest for sustainable competitive advantage.

5.12 Stage 9: PFM Improvement Project Implementation

The implementation of stage nine is divided into four sections which are illustrated in Figure 5.13. Each section is associated with an implementation worksheet which is included in the PFM implementation workbook as shown in Appendix D. The following discussion will introduce the aim and functionality of each section.

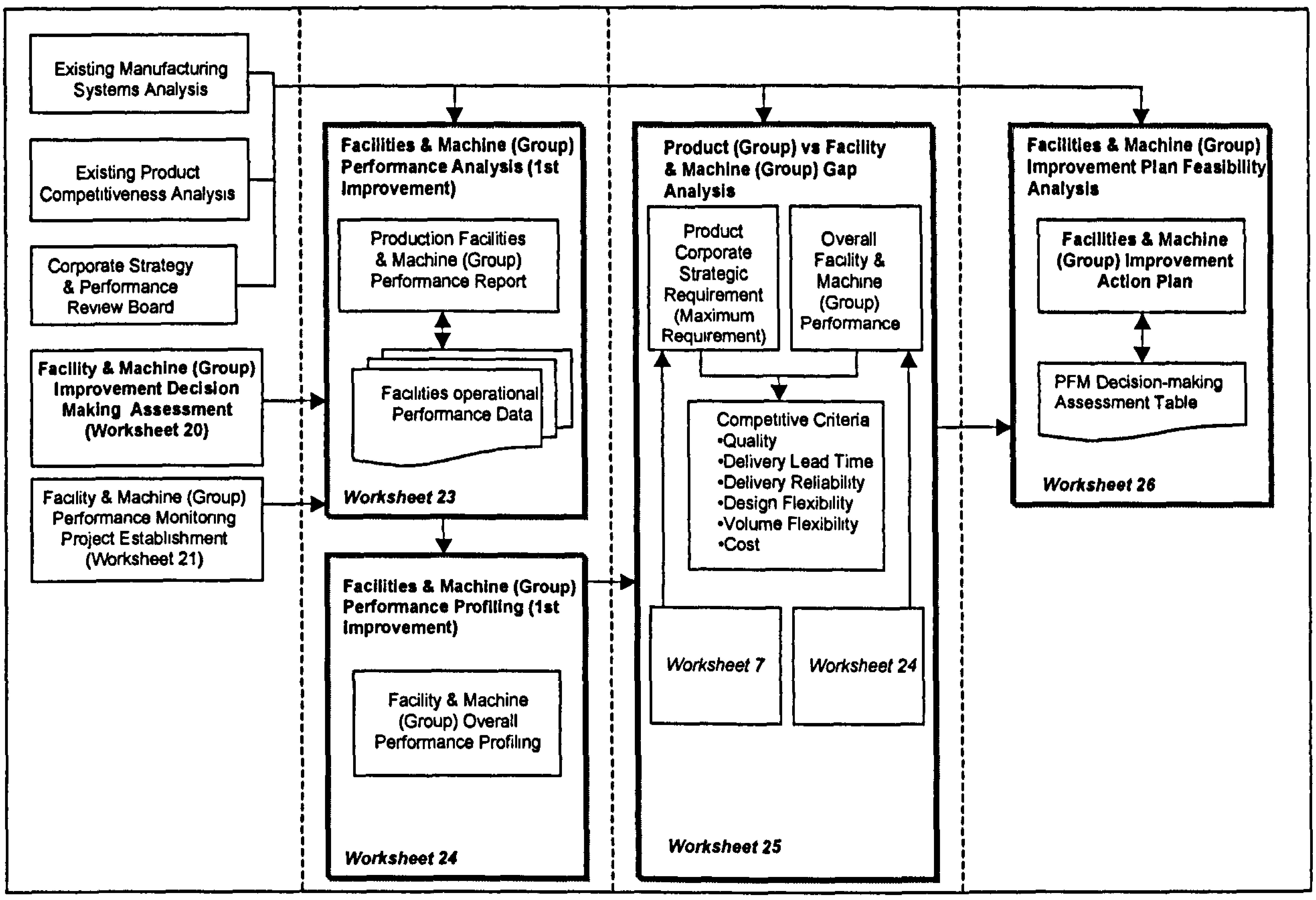


Figure 5.13 Facility Performance Improvement Plan Implementation Flow Chart

5.12.1 Section 23: Facilities & Machine (Group) Performance Analysis (for 1st Stage Improvement)

The development of this section is to record the operational performance data of each facility and machine (group) with respect to each PM and PI. In order to be consistent to the strategic requirement, the items of the PM and PI are the same as those listed in Table 5.5 (as in section 16).

5.12.2 Section 24: Facilities and Machine (Group) Performance Profiling (for 1st Stage Improvement)

The development of this section is to provide the gap analysis between the performance of facilities and the requirement of overall facilities after the improvement plan is executed. The procedure is the same as implemented in section seventeen. The overall performance of each machine (group) can be determined by six criteria: quality, delivery reliability, delivery lead time, design flexibility, volume flexibility, and cost. The performance of each criterion is an accumulated result from the performance of the sub-ordinary PM and PI. The relationship between these competitive criteria, PM and PI, is defined by the hierarchy of PFM PMS. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirement. The implementation process is the same as the analysis of manufacturing system performance profiling in section five. The UV value calculation and polar diagram can also be used for analysis in this section

5.12.3 Section 25: Product (Group) and Facility and Machine (Group) Performance Gap Analysis (for 1st Stage Improvement)

The development of this section is to analyse the performance gap between product (group) requirement and facility and machine (group) performance achievement after the improvement plan is implemented. If there are gaps, it means there is space for further improvement. The larger the gap the more improvement action will be required in that criterion. The method is the same as applied in section six which is to compare the maximum UV value from the current facility and machine (group) overall performance profiling (data derived from section 16) and the maximum UV value from product (group) requirement profiling (data derived from section 3). The deviation will prioritise the improvement plan with respect to the competitive criteria. The larger the gap in a specified competitive criterion the more improvement actions that should be required. A polar diagram can also be used for clear presentation of the deviation.

5.12.4 Section 26: Facilities and Machine (Group) Improvement Plan

The development of this section is to assess the feasibility of the choice of the improvement options in production facilities management. The process is to assess the different possibilities of maintaining, enhancing or replacing current facilities and machines (groups) so as to match the production requirement. This analysis also discusses the relations between these options with respect to the strategic requirements and policy decision-making areas. This analysis is based on the identification of the weight of different options from the Production Facilities Management Decision-Making Assessment Quick Hit Table shown in Appendix I. However, whether this improvement plan is required or not depends on the assessment that is implemented by the review board.

There are two typical implementation circles in practical PFM operation. To assess the feasibility of establishing new facilities, enhancing and/or replacing current facilities, the PFM framework is implemented from section one to section 20. To assess the performance and feasibility of maintaining current facilities, the PFM framework is operated in a circle from section 11 to section 26. The difference is the former should be initiated from an assessment of the strategic requirements and the latter is concerned with achieving and supporting the current strategic requirements.

5.13 Conclusion

This chapter has illustrated the development of the nine-stage and 26–section implementation process. The developed process provides a systematic, step-by-step implementation process to link formulation of the manufacturing strategy, monitoring and assessment of the performance of current facilities, and decision-making of the improvement action plan together. The following chapter is concerned with the evaluation of the developed PFM framework and implementation process.

CHAPTER 6

EVALUATION OF THE STRATEGICALLY DRIVEN PRODUCTION FACILITIES MANAGEMENT (PFM) FRAMEWORK

6.1 Introduction

This chapter describes the evaluation of the strategically driven PFM framework developed in chapter 5. An evaluation programme was established and executed. The intention of the evaluation was to assess the value of the proposed solution in capturing the strategic requirements of the corporate strategy, transforming them into the aims of production facilities management, and implementing them with an appropriate facilities management process.

6.2 Establishment of the Evaluation Programme

This section explains the criteria used for evaluation of the PFM implementation process and the details of the evaluation programme.

6.2.1 Evaluation Criteria

Any evaluation should meet the criteria of utility, feasibility, propriety and technical adequacy (Robson, 1993). Utility refers to the overall usefulness of the approach. Feasibility refers to the practicality of using the approach. Propriety emphasises that an evaluation can only be carried out fairly. Given reassurances about utility, feasibility and proper conduct, the evaluation must then be carried out with technical skill and sensitivity. In order to assess the developed PFM framework and implementation process, these criteria are the main features of the evaluation process.

6.2.2 The Evaluation Process

Czaja *et al* (1995) has identified five general stages in the development and completion of a survey. These are as follows:

1. Survey design and preliminary planning
2. Pre-testing
3. Final survey design and planning
4. Data collection
5. Data coding, data-file construction, analysis and final report

Morris *et al* (1987) has developed some basic steps in developing a performance test for programme evaluation. They state the following:

1. Determine the outcomes to be measured
2. Develop a blueprint for the test
3. Write the test items
4. Review and edit the items
5. Field test the items
6. Obtain reliability and validity data

The factors developed by Morris *et al* (1987), Robson (1993), and Czaja *et al* (1995) help in identifying the requirements of evaluation and the design of the evaluation process which is illustrated in Figure 6.1.

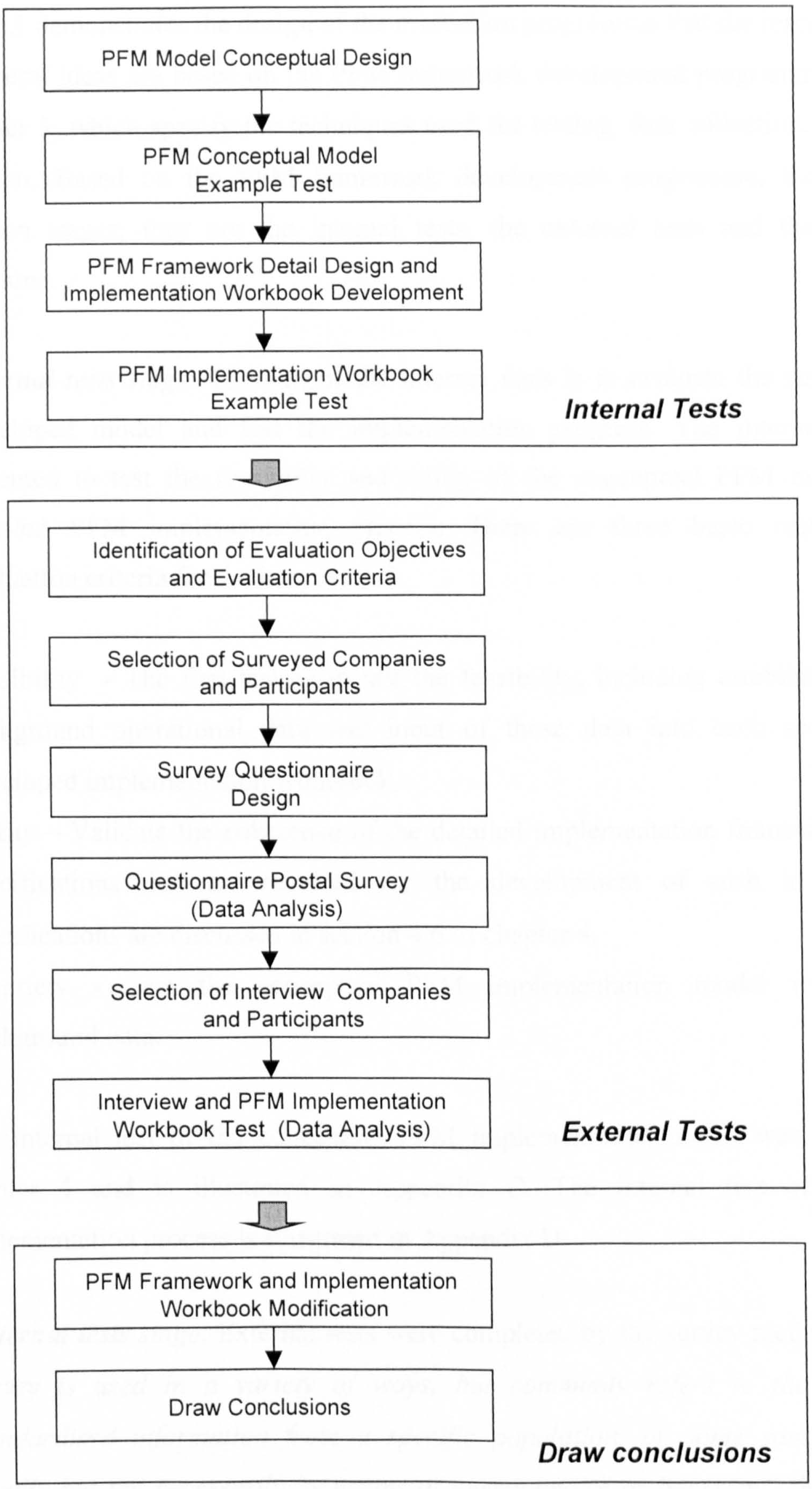


Figure 6.1 PFM Framework and Implementation Process Evaluation Programme

Figure 6.1 demonstrates the design of the evaluation programme that the research adopted. The general ideas are based on the PFM framework development programme introduced in chapter 3, which specify the techniques used for testing, data collection, analysis and evaluation. Based on the PFM framework development programme, there are three evaluation stages; they are the internal tests, the external tests and the drawing of conclusions.

1. ***Internal tests stage***: The aim of the internal tests is to evaluate the structure of the developed model and test the implementation progress. The internal tests were executed to test the feasibility and utility of the conceptual PFM model and the detailed PFM implementation process. There are three basic requirements of evaluation criteria for the internal test.

1) Feasibility - The first task is to test the feasibility, including establishment of the background operational data and input of these data into each section of the developed implementation workbook.
2) Utility – Validate the coherence of the detailed implementation framework with the specifications that are required for the development of such a model. The specifications are discussed in section 4.6 of chapter 4.
3) Propriety - Test the conceptual PFM implementation model with example background data.

The internal test of the conceptual PFM implementation model was introduced in chapter 4 and is illustrated in Appendix C. The internal test of the detailed implementation process is illustrated in Appendix D.

2. ***External tests stage***: External tests were completed by the survey methodology. "*The survey is used in a variety of ways, but commonly refers to the collection of standardised information from a specific population, or some sample from one, usually but not necessarily by means of questionnaire or interview*" (Robson, 1993). The external tests that were executed in the research were a postal questionnaire survey and a face-to-face interview survey. There are three basic requirements of evaluation criteria for the external tests:

- *Feasibility* - Collect more information from pragmatic applications in the real world so as to discover whether or not there is a deviation between the academic research and the practical application. Modifications are needed if there is a deviation. The key point is the collection of the key parameters that are used to measure the performance of business and facilities in practical applications. The aim of this identification is to condense the number of measurements. As a general rule, if a team has more than 15 measurements, it should take a fresh look at the importance of each one (Meyer, 1994).
- *Utility* – Test the overall usefulness of the PFM framework. The aim of the test on this criterion is to understand the possibility that the PFM framework can be used by the interviewed companies and what kind of improvement it will require. In reality, to different company backgrounds in particular, to the different types of production facilities they are using, the framework may need adjustment.
- *Propriety* – For the purpose of comparison, the external test uses the same example background data as used in the internal test. The example case is especially used in discussion with the interviewers to test the feasibility and utility of the detailed PFM implementation workbook.

The external tests also aim to use the survey techniques for the validity test and modification of the PFM framework as a whole.

3. ***Draw conclusions***: The conclusion of the evaluation is to summarise the findings on the evaluation of the PFM framework implementation process. This section concerns the performance of the developed PFM framework in relation to the specifications outlined in chapter 4, to the criteria of feasibility, utility, and usability, and to the research aim. In this section, limitations to the success of the approach are also briefly discussed.

6.3 The Methods and Techniques Applied in the Evaluation Process

In order to ensure the evaluation process can be properly carried out, several methods and techniques are applied for external tests.

6.3.1 Example Test of the Detailed Implementation Workbook

The first stage of the evaluation is to test the PFM framework and implementation workbook by an internal test. This internal test was accomplished by sequentially following a series of steps in the implementation workbook as Appendix D.

All of the performance measures and indicators applied in the example worksheets are typical ones which are derived from the reviewed literature. Different companies should make their own decisions on the choices of the proper parameters so as to be compatible with their background. After the internal tests, the PFM framework was tested to be workable through these example operational data. However, these example operational data are ideal for explaining the implementation process.

6.3.2 Questionnaire Survey

The objective of the postal questionnaire survey was to understand the deviation between the findings of academic research, internal tests and practical applications. The questionnaire letter and questionnaire are shown in Appendix J and Appendix K. The questions are mainly about the applied management strategies and techniques, performance measures for the business and facilities management, and the strategic concerns in decision-making of production facilities management that are used by manufacturers in reality. The information collected by the postal questionnaire survey can provide a generic understanding about the situation of PFM that is implemented by present manufacturers. The analysis of the usage of the management strategies and methodologies and the decision policy areas used by present manufacturers will help the process of formulating strategy of the PFM framework development. The understanding of the feasibility and acceptability of the recommended performance measures and indicators will help the establishment of the facilities performance assessment of the PFM framework development.

6.3.3 Interview Survey

The purpose of the interview survey was to understand the practical application in production facilities management by manufacturers at the moment. The designated interviewing companies were selected from the companies that returned the postal questionnaire survey. The main information to be collected were the strategies, performance measures for the business and facilities management, and decision-making areas in production facilities management that are used by manufacturers at present. There were two objectives for the interview survey:

1. *Evaluation of the developed PFM framework* – This was achieved by discussing the step-by-step process of the PFM implementation framework with the interviewees. This also searched for the possibility of whether the interviewed company would support the practical operation data for testing the framework or not.

2. *Test of the PFM implementation workbook* – This was accomplished by using the same example case and background data as the internal test and reviewing the feasibility and utility with the selected interviewers. The purpose of the face-to-face survey was to discuss the validity of the PFM framework and identify the acceptability of these competitive criteria and parameters for monitoring the performance of business and facilities in reality. This test also tried to find out any way of improving the simplicity of the PFM framework.

6.4 Questionnaire Design and Survey

6.4.1 Characteristics of Surveyed Companies

The choice of the appropriate companies was one of the steps both in the questionnaire and interview surveys. The surveyed candidate companies were chosen from the U.K. companies information (Kompass, 1998-1999), the companies information service software (OneSource, 1996) and some companies in Taiwan R.O.C. The characteristics of the companies surveyed are:

- Company: Small to Medium
- Product (Group): Sub-contractor manufacturers of aircraft, automobiles, and sub-contract machinery.
- Employees: 100-500
- Company location: in U.K. and Taiwan R.O.C.
- Survey sample justification: Although numerous manufacturing industries could have been used in this study, the author's prior knowledge and experience of the above industries led him to believe they were suitable for the PFM framework.

6.4.2 Questionnaire Design

The contents of the questionnaire were designed and reviewed in Cranfield University. The questionnaire is shown in Appendix K.

6.4.3 Discussion and Findings of the Questionnaire Survey

The results and data analysis of the postal questionnaire survey are shown in Appendix L. This section describes the main results and presents a discussion of the findings. In total, 161 companies were selected for the postal questionnaire survey; 12 companies answered the questionnaires, including three companies from Taiwan. Even though the response was rather low, the data was analysed and has provided valuable information for the evaluation of the PFM framework. The percentage values shown are the percentage of the companies who answered the questionnaire. The results and discussion are summarised as follows:

Question 1: The strategies and methodologies used in manufacturing business

This question asks about the strategies and methodologies that are currently used by manufacturing industry. Each different strategy and methodology has its own special concepts and implementation requirements. The understanding and usage of these concepts in practical application will help in evaluating the basic concepts of that were adapted from literature and their manipulation into the design the PFM framework. The aim of the research is to design the available management theories and techniques of facilities management into the PFM framework and narrow the gaps between the academic research and practical application of them. The listed strategies and methodologies are the typical but not exhaustive ones in academic research. The survey result for question one is shown in the table 6.1.

Table 6.1 Strategies and Methodologies Usage Analysis Table

Strategy/Methodology	Used Currently (%)	Will use in the future (%)	Not aware of at the moment (%)	No answer (%)
TQM (Total Quality Management)	10 (83%)			2 (17%)
JIT (Just In Time)	8 (67%)	2 (17%)		2 (17%)
Lean Manufacturing	7 (58%)		2 (17%)	3 (25%)
TPM (Total Productive Maintenance)	6 (50%)	1 (8%)	1 (8%)	4 (33%)
WCM (World Class Manufacturing)	6 (50%)		1 (8%)	5 (42%)
CMMS (Computerised Maintenance Management System)	5 (42%)	1 (8%)		6 (50%)
MRP (Material Requirement Planning)	4 (33%)	1 (8%)		7 (59%)
MRPII (Manufacturing Resource Planning)	4 (33%)	3 (25%)		5 (42%)
BPR (Business Process Reengineering)	4 (33%)	1 (8%)	1 (8%)	6 (50%)
CE (Concurrent Engineering)	2 (17%)	2 (17%)	1 (8%)	7 (59%)
CALS (Computer Aided Logistics Support)	1 (8%)	1 (8%)	4 (33%)	6 (50%)
RCM (Reliability Centred Maintenance)		2 (17%)	1 (8%)	9 (75%)
ILS (Integrated Logistics Support)		1 (8%)	3 (25%)	8 (67%)

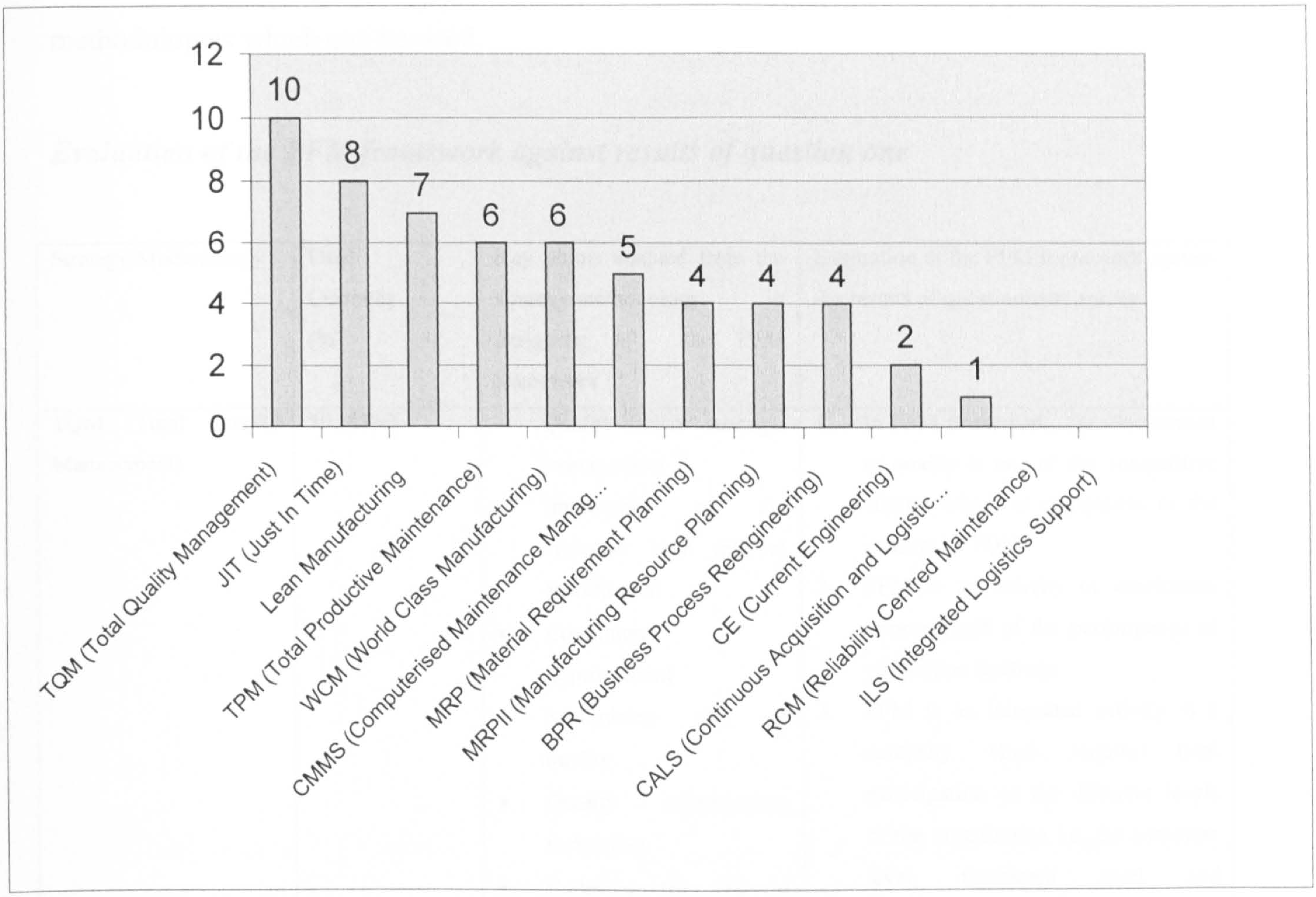


Figure 6.2 Analysis of Usage of Strategies and Methodologies

From Figure 6.2, it can be seen that TQM and JIT are the most popular strategies in use. This result illustrates that the requirements on quality, delivery reliability and delivery lead time are the most strategic requirements. Maintenance and resource planning are gradually becoming important, in particular the concept of TPM for facilities management is accepted by most of the manufacturers. However, even though the concepts of CALS, RCM and ILS are beneficial in monitoring the performance of facilities and supporting logistics, the manufacturers are still not aware of the need for reliable facilities and the benefit of EDI (Electric Data Interchange) in their management strategy. Several companies do not have opinions on the usage of listed strategies / methodologies. The main reason was that the participants do not understand the significance of these strategies and methodologies and the benefits they can provide. However, these unused terms also showed that there are gaps between academic research and practical application. These gaps can be further studied to fit in the practical requirement of the manufacturers. The items listed in the questionnaires are typical, but not exhaustive, of the strategies and methodologies which can be used.

Evaluation of the PFM framework against results of question one

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
TQM (Total Quality Management)	10 (83%)	• Quality-driven strategic management • Importance of the customer both internal and external • Continuous improvement • Minimising cost of quality • Quality improvement techniques • Reducing the risk of failure • The need of scientific knowledge • Total participation • Dahlgaard *et al* (1998) Logothetis (1992)	1. In PFM framework, the requirement of quality is one of the competitive criteria which is compatible to the concept of TQM 2. PFM is an activity of continuous improvement of the performance of production facilities 3. PFM is an integrated activity in a company which requires total participation of the different levels of the organisation i.e. the corporate level, functional level and operational level. 4. The parameters designed for monitoring the performance of business and facilities in PFM framework can be implemented in reality 5. Documentation and standardisation of the PFM process are important in practical implementation

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
JIT (Just In Time)	8 (67%)	• Minimising inventory • Reducing delivery lead time and promote delivery reliability • Attacking waste • Improving labour flexibility • Designing for manufacturing efficiency • Maintenance of facilities • Cheng *et al* (1996)	1. Delivery reliability, delivery lead time and cost are important strategic requirements in JIT. 2. These requirements have been designed into the PFM framework to be the important competitive criteria to monitor the performance of the business. 3. The key points adapted from the concept of JIT are also designed into the PFM framework as a whole
TPM (Total Productive Maintenance)	6 (50%)	• Total employee involvement • Minimising six losses of the facilities • Parameters to monitor the performance of facilities • Strategic and local improvement teas • Monitoring of the performance of business and maintenance of the facilities	1. The parameters adapted from TPM concept have been designed into the PFM framework for monitoring the performance of facilities. 2. From survey results, these measures have been accepted and some companies have being already using them in manufacturing industry. 3. The PFM framework should be workable in reality in particular the performance monitoring

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
Lean Manufacturing	7 (58%)	• Dependable, effective equipment • Minimising work-in-process and finished inventory • Sekine *et al* (1998)	1. Reliable facilities is a vital factor in PFM 2. Reliability, maintainability and availability are vital performance measures in PFM
WCM (World Class Manufacturing)	6 (50%)	• Reviewing key elements of business strategy formulation • Mission statement • SWOT Analysis • Statement of quantified aims and objectives • Detailed operational plan • Monitoring of the performance of business and facilities • WCM means the best in: a) Product design and performance b) Quality and reliability c) Least manufacturing cost d) Innovative products e) Shorter lead time and more reliable delivery performance f) Customer service • Todd (1995)	1. Manufacturing strategy formulation process of PFM framework is pragmatic and useful to manufacturing industry 2. The competitive criteria designed in PFM framework which are adapted from WCM can be used in reality

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
CMMS (Computerised Maintenance Management System)	5 (42%)	• Keep minimum maintenance cost • Meet quality requirements • Meet availability of critical equipment • Provide and maintain adequate facilities for operation • Provide effective and trained supervision • Wireman (1994, 1998)	1. Producing good, useful data is the goal of any CMMS. 2. The performance data which are recorded and collected by PFM framework provide basic requirements of CMMS. After check with the surveyed companies, over 50 % of the companies do not use CMMS mainly because the problem of financial issue, assessment of the functionality of the CMMS on the market, and the integration with the existing management information system.
MRP (Material Requirement Planning)	4 (33%)	• Inventory management • BOM (Bill of Material) • Master Production Schedule (MPS) • Capacity planning and analysis at the strategic level and operational level • Product group forecast • Toomey (1996)	1. Capacity Requirements Planning (CRP) is both the strategic requirement and important area in decision m-making of PFM 2. The measures for capacity and work load management are available in PFM framework design

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
MRPII (Manufacturing Resource Planning)	4 (33%)	• Based on MRP and increase financial planning and simulation capabilities • Inventory accuracy • BOM (Bill of Material) accuracy • Delivery performance • System stability • Capacity planning and analysis at the strategic level and operational level • Product group forecast • Minimising cost • Toomey (1996)	1. Capacity Requirements Planning (CRP) is both the strategic requirement and important area in decision m-making of PFM 2. The measures for capacity, cost and work load management are available in PFM framework design
BPR (Business Process Reengineering)	4 (33%)	• Integrated Product Development (IPD) • Optimising product and process in a systematic, and practical manner. • Establish product and process design criteria • Understanding manufacturing process and materials • Understanding failure processes and relationship to product design • Understanding support processes • Designing use and manufacturing process capability • Hunt, (1993)	1. The implementation of PFM can match the basic requirements of BPR in particular from the support of the efficient and effective production facilities 2. From the surveyed results, only 33% of the companies are using "re-engineering" as their strategy, the main reason is there is a lack of detailed implementation guide. PFM framework can improve the gap between them.

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
CE (Concurrent Engineering)	2 (17%)	• Time to market is the key competitive issue in manufacturing industry • Well designed, high quality, low price and decreasing lead time are globally demanded • Promotion of team spirit • Integration of design and manufacturing support • Design for Manufacturing (DFM) • Syan *et al* (1994)	1. DFM approach requires the data of PFM for the communication between the designers and manufacturers, and to integrate manufacturing process design and product design to ensure the best matching of needs and requirements 2. The PFM framework can help implementation of CE
CALS (Computer Aided Logistics Support)	1 (8%)	• Based on the theory of ILS (Integrated Logistics Support) • EDI (Electronic Data Interchange) • Minising the Life Cycle Cost (LCC) of the facility • Breakdown the LCC and develop the performance measures to monitor the performance of any equipment throughout their life cycles	1. The result indicates only one company uses the CALS as their strategy which highlighted the gap between the academic research and practical application. 2. The reason has been checked with these companies which is they do not understand the contents and implementation of the ILS. However, the companies accepted that the performance measures designed in PFM framework are available throughout the life cycle of the facility

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
RCM (Reliability Centred Maintenance)	0 (0%)	• Higher plant availability and reliability • Greater safety • Better product quality • No damage to environment • Longer equipment life • Greater cost effectiveness • Moubray (1997)	1. The result indicates that the surveyed companies do not use the RCM to be their facilities management strategy. 2. The reason has been checked with the companies which is they do not understand the contents and how to implement it. 3. The other reason is the surveyed companies considered the RCM is more suitable for the manufacturers of the machines and equipment than the practitioners. 4. The result indicates there is a gap between the academic research and practical application of it. 5. The parameters designed in PFM framework are acceptable and available to monitor the performance of facilities.

Strategy/Methodology	Used Currently (%)	Key points adapted from the strategy/methodology in designing of the PFM framework	Evaluation of the PFM framework against the results of questionnaire survey
ILS (Integrated Logistics Support)	0 (0%)	• Minising the Life Cycle Cost (LCC) of the facility • Breakdown the LCC and monitor the performance of any equipment throughout their life cycles	1. The result indicates the surveyed companies do not use the strategy or methodology related to ILS which highlighted the gap between the academic research and practical application. 2. The reason has been checked with these companies which is they do not understand the contents and how to implement the ILS. However, the companies accepted that the life cycle management and LCC analysis designed in PFM framework should be beneficial to any manufacturing business.

Question 2: The policy areas to be considered in strategy formulation

This question is asking about the application of policy decision-making areas in formulating the manufacturing strategy. From the academic viewpoint, there are some typical areas which should be considered in formulating manufacturing strategy. This question also aims to investigate the deviation of these policy areas between academic research and practical application by the manufacturers. The reason being that to define the requirements for formulating strategy and to define the strategic objective in each area will guide the process of formulating a strategy comprehensively. This is important because the purpose of the PFM is to support all of the strategic objectives in each policy area to be accomplished. The survey results are shown in the following table. From the results, a recommended priority of each area in formulating corporate strategy is also shown in the analysis table.

Table 6.2 Policy Decision Making Areas Analysis Table

Policy Decision Making areas which are taken into consideration in formulating corporate strategy	Yes (%)	No (%)	None (%)
Capacity	12 (100%)		
Facilities	11 (92%)	1 (8%)	
Process and Technology	11 (92%)		1 (8%)
Production Planning and Control	10 (83%)	1 (8%)	1 (8%)
Supplier Relations	9 (75%)	3 (25%)	
Human Resources	9 (75%)	3 (25%)	
Quality Systems	9 (75%)	2 (17%)	1 (8%)
Performance Measurement	9 (75%)	2 (17%)	1 (8%)
Organisation	9 (75%)	2 (17%)	1 (8%)
New Product Introduction and Scope	8 (67%)	4 (33%)	
Vertical Integration	7 (58%)	4 (33%)	1 (8%)

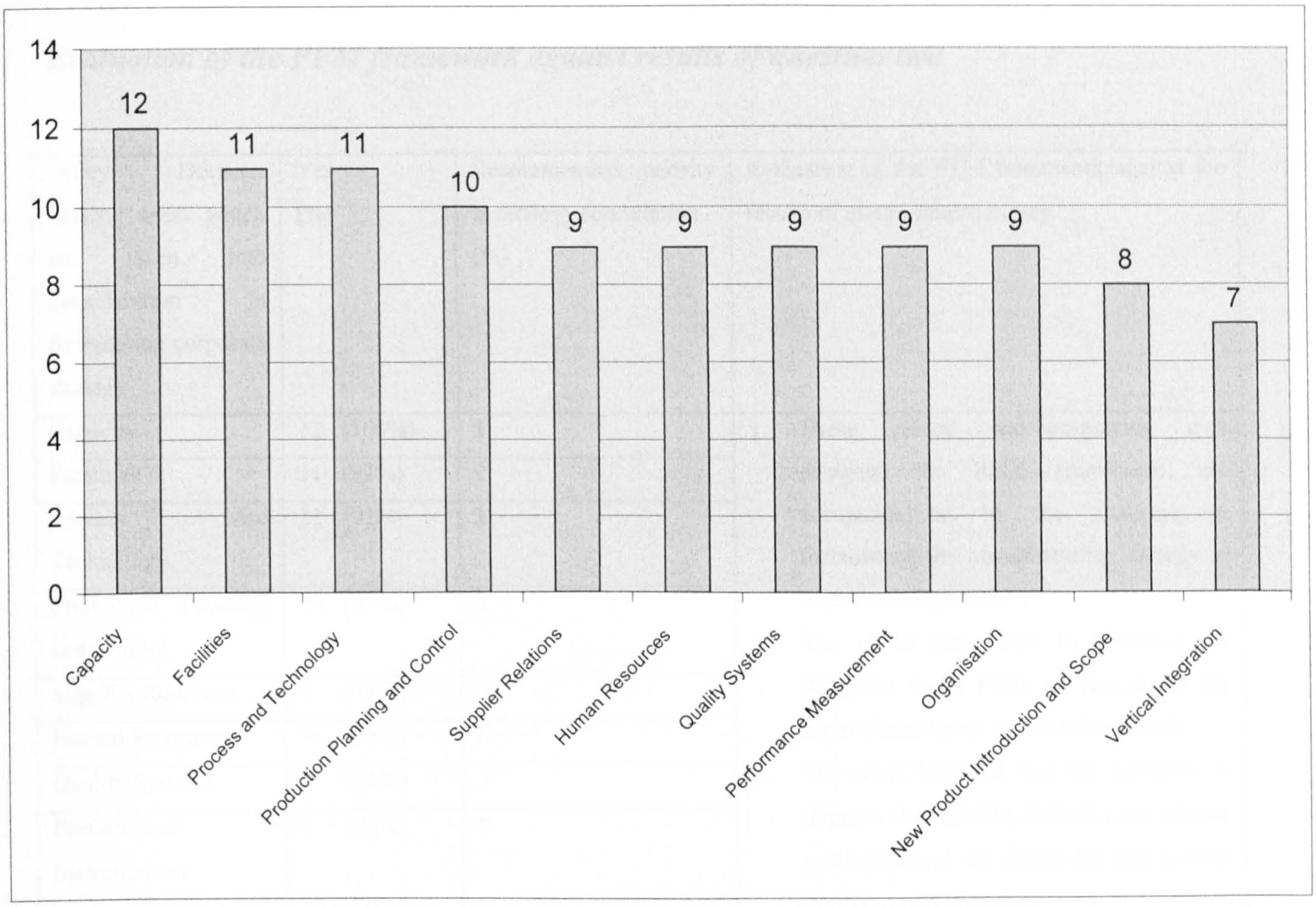


Figure 6.3 Analysis of Usage of Decision Making Areas

Figure 6.3 shows that all of the recommended areas are accepted by the surveyed companies to be a factor in formulating their manufacturing strategy. This result indicates that there is not much gap between academic research and practical application about the concerns in strategy formulation. In reality, the capacity, facilities and process and technology take care of the main responsibility of production of the products. It is obvious that appropriate and reliable facilities are essential otherwise the products could not be produced at the right quantity and quality required. This result also highlights that there is a strong link between reliable facilities and maintenance, and customer requirements. This result illustrates that facilities management should be one of the strategic concerns in corporate strategy. It is recommended to set strategic objectives in each area so as to accomplish a competitive strategy.

Evaluation of the PFM framework against results of question two

Policy Decision Making areas which are taken into consideration in formulating corporate strategy	Yes (%)	Recommended priority in strategy formulation (%)	Evaluation of the PFM framework against the results of questionnaire survey
Capacity	12 (100%)	1	1. These eleven decision-making area designed in PFM framework are acceptable to be the concerns in formulating the manufacturing strategy in manufacturing industry. 2. The result also helps to prioritise the decisions to be made in choices of the improvement plan in PFM framework. 3. The result indicates that the decisions to improve the capacity, facilities and process and technology are always the first priority in investment in reality.
Facilities	11 (92%)	2	
Process and Technology	11 (92%)	3	
Production Planning and Control	10 (83%)	4	
Supplier Relations	9 (75%)	5	
Human Resources	9 (75%)	6	
Quality Systems	9 (75%)	7	
Performance Measurement	9 (75%)	8	
Organisation	9 (75%)	9	
New Product Introduction and Scope	8 (67%)	10	
Vertical Integration	7 (58%)	11	

Question 3: The usage of business competitive criteria

From the literature review, it was seen that traditional financial based performance measures actually inhibited improvement activities. By the last years of the twentieth century, companies were starting to develop and implement new approaches for motivating manufacturing and design excellence (Kaplan, 1990; and Maskell, 1991). This question is asking about the parameters which can be used to measure business competitiveness. The recommended competitive criteria are adapted from the literature survey and these are typical but not exhaustive ones. The weight of importance and priority of them have also been asked so as to understand the ratio of usage and understanding of these measures in manufacturing industry. The result is shown in the following table.

Table 6.3 Competitive Criteria Usage Analysis Table

Competitive Criteria	Use	Not use	Weight of importance (points per each score)					Total weight of importance of each criterion (Points after accumulation)	Priority of the importance of each competitive criterion
			Negligible (1)	Low (2)	Acceptable (3)	High (4)	Very High (5)		
Quality	12				1	1	10	57	1
Cost	12				1	5	6	53	2
Delivery Reliability	12				1	9	2	49	3
Price	10	2			3	3	4	41	4
Delivery Lead Time	10	2		1	3	6		35	5
Speed	8	4			1	5	2	33	6
Volume Flexibility	8	4			4	4		28	7
Design Flexibility	5	7			3	1	1	18	8
Service	1					1		4	9

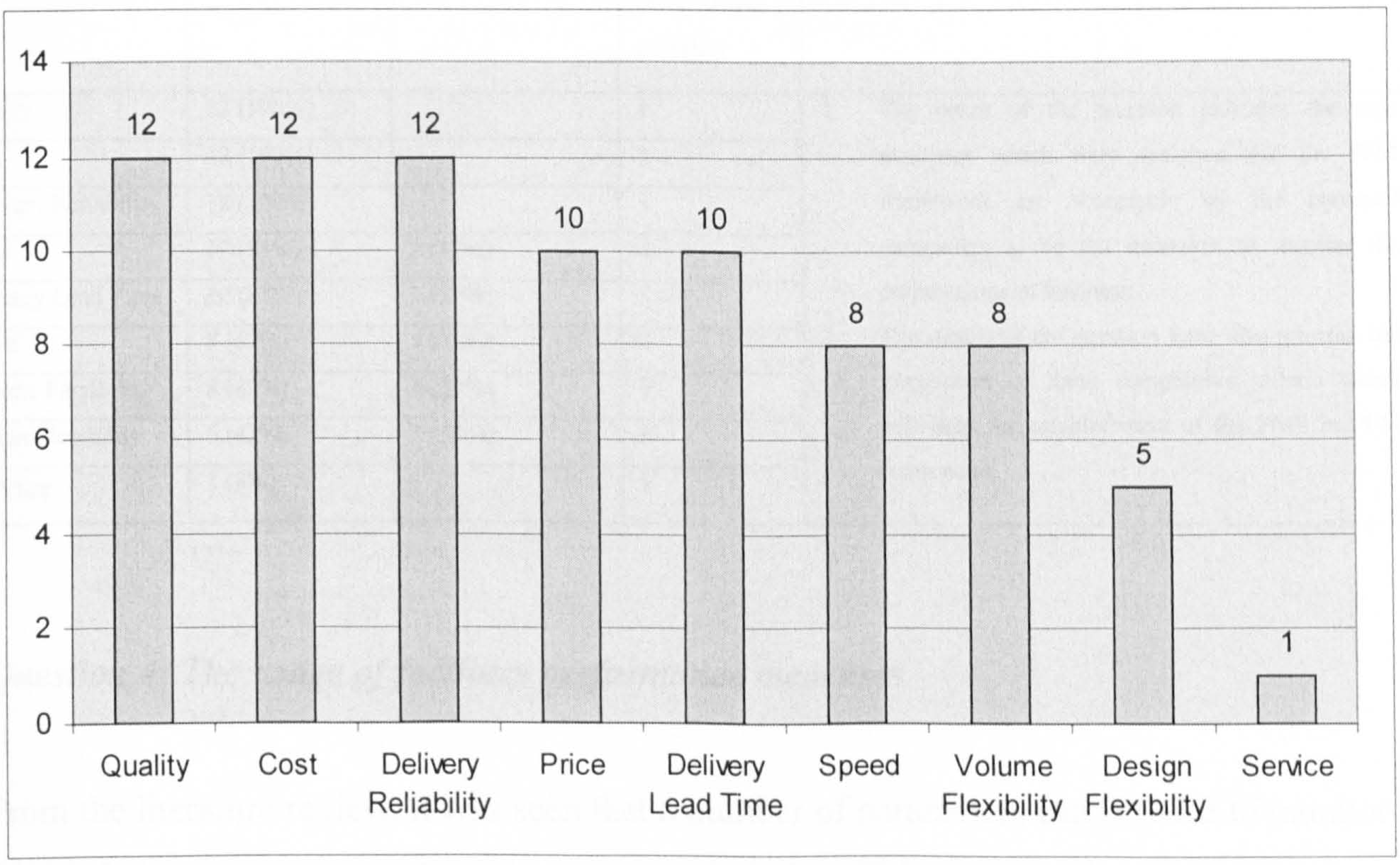


Figure 6.4 Analysis of Usage of Competitive Criteria

From the postal survey, it can be seen that all of the recommended parameters have been used by the surveyed companies as criteria to assess the performance of the business. This result illustrates that there is not a significant gap between academic research and practical application. In implementing PFM framework, the priority of the competitive criteria sequentially decides the strategic objectives related to these criteria. In the PFM framework, the priority of these competitive criteria will provide the basis to establish the mission statement of the business. This result also shows a generic tendency of the priority of competitive criteria in manufacturing business. However, every company can establish their own priority of competitive criteria which is based on the environment of such a company. The priority of these competitive criteria provides the strategic requirements of the corporate level in a performance measurement system in the PFM framework.

Evaluation of the PFM framework against results of question three

<table>
<tr><th>Competitive Criteria</th><th>Use (%)</th><th>Not Use (%)</th><th>Priority of the importance of each competitive criterion</th><th>Evaluation of the PFM framework against the results of the questionnaire survey</th></tr>
<tr><td>Quality</td><td>12 (100%)</td><td></td><td>1</td><td rowspan="9">1. The result of the question indicates the nine measures which were designed into the PFM framework are acceptable by the surveyed companies to be the measures to monitor the performance of business.
2. The results of the question three also priortise the importance of these competitive criteria which will help the establishment of the PMS in PFM framework</td></tr>
<tr><td>Cost</td><td>12 (100%)</td><td></td><td>2</td></tr>
<tr><td>Delivery Reliability</td><td>12 (100%)</td><td></td><td>3</td></tr>
<tr><td>Price</td><td>10 (83%)</td><td>2 (17%)</td><td>4</td></tr>
<tr><td>Delivery Lead Time</td><td>10 (83%)</td><td>2 (17%)</td><td>5</td></tr>
<tr><td>Speed</td><td>8 (67%)</td><td>4 (33%)</td><td>6</td></tr>
<tr><td>Volume Flexibility</td><td>8 (67%)</td><td>4 (33%)</td><td>7</td></tr>
<tr><td>Design Flexibility</td><td>5 (42%)</td><td>7 (58%)</td><td>8</td></tr>
<tr><td>Service</td><td>1 (8%)</td><td></td><td>9</td></tr>
</table>

Question 4: The usage of facilities performance measures

From the literature review, it was seen that a number of parameters can be used to monitor the performance of a manufacturing system operation. This question is trying to analyse whether these parameters found from academic research are available in practical manufacturing industry. The weight of importance of each parameter has been ascertained so as to prioritise these parameters. The results of this question also provides an idea about the methodology used to link the machine (group) performance measures with the business competitiveness criteria. The total results are shown in the following table and the data analysis of the usage and relations between these Performance Measures (PM) and Performance Indicators (PI) will be demonstrated in Appendix L.

Table 6.4 Usage of Performance Measures and Performance Indicators Analysis Table

Performance Measures (PM)	Performance Indicators (PI)	Used	Not used	Weight of Importance			Total Weight	Priority of the Importance of each PI
				Low	Medium	High		
Quality	Monthly Scrap Cost	12			3	9	33	1
	Quality Rate	10	2		2	8	28	2
	Monthly Rework Cost	11	1	1	3	7	28	3
	Rate of Customer complaints on Service	7	5		2	6	22	4
	Weekly Process Yield	6	6		2	4	16	5
	Warranty Claims	4	7			4	12	6
Availability	Equipment Breakdown Frequency	10	2		1	9	29	1
	Equipment Availability	10	2		2	8	28	2
	Replacement Frequency	2	8		1	1	5	3
Capacity	Efficiency	9	3		2	7	25	1
	Overall Equipment Effectiveness	8	3		2	6	22	2
	Output / Throughput per Machine Hour	7	5		3	5	21	3
	Utilisation (Actual Output / Designed Capacity)	7	5		2	5	19	4
	Capacity Ratio (Actual Hours Worked / Budget Standard Hours)	6	6		2	4	16	5
	Percentage of Full Capacity Normally Available	7	5	1	4	2	15	6
	Machine Hours / Year	5	7	1	2	2	11	7
Cost	Total Variable Cost / Total Sales	10	2		4	5	23	1
	Total Fixed Cost / Total Sales	10	2		5	4	22	2
	Payback Period of Each Machine	9	3		5	4	22	3
	Cost per Operation Hour	8	4		3	5	21	4
	Utility Consumption	7	5	1	2	4	17	5
	Life Cycle Cost of Equipment	5	7		3	2	12	6
	Variety of Products and Services	4	8		2	2	10	4

Performance Measures (PM)	Performance Indicators (PI)	Used	Not used	Weight of Importance			Total weight	Priority of the importance of each PI
				Low	Medium	High		
Cost	Average Capacity and Maximum Capacity	5	7			3	9	5
	Monthly Average Changeover Time	4	8		3	1	9	6
Maintainability	Mean Down Time (MDT)	8	5	1	2	5	20	1
	Mean Time Between Maintenance (MTBM)	5	7			6	18	2
	Monthly Plant Up Time (%)	6	6		2	4	16	3
	Mean Time To Repair (MTTR)	5	7		3	3	15	4
	Mean Preventive Maintenance Time	6	6		3	3	15	5
	Monthly Unscheduled Downtime Percentage	6	6		3	3	15	6
	Monthly Machine Up Time (%)	6	6	1	1	4	15	7
	Mean Time Between Replacement (MTBR)	4	8		1	4	14	8
	Utilisation of Maintenance Personnel	5	7		3	2	12	9
	Monthly Scheduled Downtime Percentage	5	6		3	1	9	10
	Mean Active Correction Maintenance Time	3	9		3	1	9	11
	Logistics Delay Time (LDT)	2	10		4		8	12
	Administrative Delay Time (ADT)	2	10		4		8	13
Financial	Profit per Year	10	2			10	30	1
	Materials	10	2		3	7	27	2
	Sales	9	3		2	7	25	3
	Labour Productivity	10	2	1	1	7	24	4
	Operation Costs	9	3		3	6	24	5
	Depreciation	9	3	1	4	4	21	6
	Net Added Value	6	6		3	3	15	7
Productivity	Net output per Employee	11	1			11	33	1
	Sales / Capital Employed	9	3		3	6	24	2
	Sales / Employee	8	4		2	6	2	3
	Sales / Fixed Assets	6	6			6	18	4
Labour	Value Added per Working Hour	6	6		1	5	17	1
	Maintenance Man Hours / Month	4	8		2	2	10	2
	Maintenance Man Hours / Operating Hour	4	8		2	2	10	3
Safety	Annual Accident Rates	11	1		2	9	31	1
	Monthly Total Incident Rate	11	1		2	9	31	2

Evaluation of the PFM framework against results of question four

From Table 6.4, it is seen that all of the recommended parameters which were designed into the PFM framework are acceptable by the surveyed companies to assess the performance of the business and operation. The listed items are typical, but not exhaustive of the parameters that can be used. The results of the questionnaire survey also help to identify the priority of each performance measure and indicator in the decision-making process of PFM. Every company should identify the proper ones based on an integrated consideration of their environment. The usage of the competitive criteria (items listed in question 3) and the performance measures (items listed in this question 4) can be used to establish the hierarchy of the PMS in PFM. The priority of these competitive criteria provides the strategic requirements of the corporate level in establishing a performance measurement system.

6.5 Results and Discussion of Interview surveys

After the questionnaire survey, six companies were selected from the companies that answered the questionnaires and would accept the interview for further discussion of the validity and implementation of the framework. These companies are described as company A to company F; three of them located in the U.K. and three of them located in Taiwan R.O.C. The face to face survey was accomplished through company visiting and discussion of the model. The survey of the companies in Taiwan R.O.C. was accomplished through visiting two of the three companies and discussing the model with company F through telephone. The results of individual interviews are given in Appendix M. The following section will describe the main conclusions and evaluation data analysis of the PFM framework, and the test of the implementation process as a whole.

6.5.1 Background of the Interviewed Companies

The background of the interviewed companies is shown in Table 6.5.

Table 6.5 Background of Interviewed Companies

Conditions	Company A	Company B	Company C	Company D	Company E	Company F
Location	U.K.	U.K.	U.K.	Taiwan	Taiwan	Taiwan
Turnover (British Pounds)	50m-75m	10m-20m	5m-10m	2m-5m	2m-5m	5m-10m
Employees	200-500	101-250	101-250	101-150	101-250	101-500
Product (Groups)	1. Metal industry 2. Electronic 3. Shower integration	Basic metal industry	Generic mechanical engineering sub-contract	Aircraft component fabrication	1. Aircraft component fabrication 2. Generic metal fabrication	Micro chip manufacturer
Nature of business	Shower unit, metal and non-metal material	Brake disc casting	Thread rolling	Chemical milling	CNC lathe	Micro chip production
	Thermal control unit	Foundry and machining	Centreless grinding	Heat treatment	CNC milling	
	Shower fitting		Milling	Electroplating	Grinding	
	Shower spray		Electroplating	Waste treatment	Planing	
	Shower peripheral component		Lathe	Painting	Boring	
			CNC lathe	Surface treatment	Reaming	
					Drilling	
					Turning	

6.5.2 Limitations of the Evaluation Programme

In implementing the evaluation programme, the six interviewed companies could not provide on-line or historic operational data due to:

1. The companies did not have operational data exactly the same as that recommended for the framework.
2. The companies did not have a performance measurement system, however they were searching for an appropriate solution for establishing a similar system.

The aforementioned barriers prohibited the implementation of the pragmatic step-by-step test of the developed framework and inputting the practical operational data for the test. The external tests are also limited by the distance between the interviewer and interviewees, also the available time of the interviewees. However, there are two kinds of accepted methods for evaluating the implementation of the PFM framework.

1. ***Evaluation of the developed PFM framework*** – This is implemented by discussing the step-by-step process of the developed PFM implementation framework with the interviewees.
2. ***Test of the PFM implementation workbook*** – This is accomplished by using the same example case and background data as the internal test and reviewing the feasibility and utility with the selected interviewees. The purpose is to discuss the validity of the developed model and identify the acceptability of these competitive criteria and parameters for monitoring the performance of business and facilities in reality. This test also tries to identify any potential improvements for the model.

6.5.3 Evaluation Results of the PFM Framework of Company A

The full results of the interview in company A are shown in the following table.

Table 6.6 Table of Evaluation Results for Company A

Evaluation Results for Company A	
Evaluation Criteria and Key Discussion	Evaluation Results
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist implementation
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purpose
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	Stylish and innovative bathroom products and integration of the peripheral facilities
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality is the most important criterion which is shown in quality products of built-in safety features, advanced styling, durability and reliability
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• Computer aided design technology • Well-trained employees • Advanced test and production facilities
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Decentralised maintenance personnel in each building with a maintenance control centre in main office of the company
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	Safety is the most important one due to a number of high-speed polishing facilities and machines
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	Multi-skilled maintenance personnel
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	Group Technology and cellular lay-out which saves on delivery time and grouping similar techniques and working skills
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• OEE (Overall Equipment Effectiveness) • Equipment availability • Quality Rate
Decision–Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	• Financial factors are still the major concerns • Non-financial performance measures can be referenced
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Rarely replacement • Maintenance is always the first priority
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Developed performance measures and indicators are acceptable • A total of 10-12 performance indicators are recommended for the purposes of simplification
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has no formal strategy formulation process

6.5.4 Evaluation Results of the PFM Framework of Company B

The full results of the interview in company B are shown in the following table.

Table 6.7 Table of Evaluation Results for Company B

Evaluation Results for Company B	
Evaluation Criteria and Key Discussion	Evaluation Results
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist practical application • The implementation process might be too long for assessing the performance of existing facilities
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purposes
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	• Precision discs and drums manufacturer • ISO 9002 qualified manufacturer
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality, service, technical support, and price
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• Computer aided design technology • Well-trained engineers and product designers • Advanced test and production facilities • SPC (Statistic Process Control) • IT (Information Technology) application
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Centralised maintenance department
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	Quality and capacity are important ones due to batch production process
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	Contract maintenance
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	• Continuous conveyor production line, moulding line, and sand control line • Three shifts working facilities which saves re-heating energy
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Capacity (5 million castings and 2 million finished parts normally) • Quality Rate • Cost • The performance measures and indicators in the developed framework provide lots of hints
Decision–Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	• Financial factors are still the major concerns • Non-financial performance measures can be referenced
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Rarely replacement • Maintenance is always the first priority • Maintenance is executed once a week which is usually arranged at the weekend
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Developed performance measures and indicators are acceptable • A total of 10-12 performance indicators are recommended for the purpose of simplification
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has no strategy formulation process

6.5.5 Evaluation Results of the PFM Framework of Company C

The full results of the interview in company C are shown in the following table.

Table 6.8 Table of Evaluation Results for Company C

Evaluation Results for Company C	
Evaluation Criteria and Key Discussion	Evaluation Results
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist practical application
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purposes
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	• Precision machined parts manufacturer • Niche in long cylinder, high volume parts • B.S 5750/2 and Q.A.S 3289/16 qualified company
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality, delivery lead time, flexibility and minimum cost
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• CAD/CAM (Computer Aided Design / Computer Aided Manufacturing) • SPC (Statistic Process Control) • FMEA (Failure Mode and Effectiveness Analysis) • Partnership with customers • Computerised scheduling planning and control
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Centralised maintenance department
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Quality and flexibility are important ones due to niche in turned parts production • Process is batch type
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	In-house maintenance except numerical control machining centres
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	• Multiple alloys turned part, brass, nylon, ferrous and stainless steel. • Three shifts working facilities which saves set-up time.
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Capacity (annually 24 million turned parts normally) • Quality Rate • Maximum manufacturing and supplier flexibility • Cost • The performance measures and indicators in the developed framework provide lots of hints
Decision–Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	• Financial factors are still the major concerns • Non-financial performance measures can be reference
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Rarely replacement – majority are conventional machines but still reliable and highly exchangeable parts • Maintenance is always the first priority
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Performance measures and indicators developed in PFM framework are acceptable • A total of 10-12 performance indicators are recommended
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has no strategy formulation process

6.5.6 Evaluation Results of the PFM Framework of Company D

The full results of the interview in company D are shown in the following table.

Table 6.9 Table of Evaluation Results for Company D

Evaluation Results for Company D	
Evaluation Criteria and Key Discussion	Evaluation Results
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist practical application
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purpose
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	• Aerospace industry • Niche in processing parts (Surface treatment, Electro plating, chemical milling, and heat treatment) • ISO9002 qualified company
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality, delivery reliability, volume flexibility and cost
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• Safety – Environment safety law requirements of local government • SPC (Statistic Process Control) • FMEA (Failure Mode and Effectiveness Analysis)
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Centralised maintenance department, contract maintenance, operator monitoring, and reactive maintenance
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Quality, capacity, maintainability and safety • Process is batch type and volume is project type
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	In-house maintenance except major issues which are out of the ability of the maintenance department such as tank liners, and heating elements of the ovens.
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	• Multiple skilled and well trained employees • Three shifts working facilities which saves the re-heating energy of the tanks, ovens, and furnaces • CALS (Computer Aided Logistics Support) and ILS (Integrated Logistics Support) application • LCC (Life Cycle Cost)
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Capacity • Quality Rate • Cost and the performance measures and indicators in the developed framework provide lots of hints
Decision–Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	Non-financial performance measures can be important in particular measures and indicators related to quality and maintainability due to the high quality requirements in the aerospace industry
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Major facilities are rarely replaced but some of the facilities are established or replaced. The decisions are made by the requirements of contract project • Maintenance is always the first priority
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Performance measures and indicators developed in PFM framework are acceptable • A total of 10-12 performance indicators are recommended
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has no strategy formulation process

6.5.7 Evaluation Results of the PFM Framework of Company E

The full results of the interview in company E are shown in the following table.

Table 6.10 Table of Evaluation Results for Company E

Evaluation Results for Company E	
Evaluation Criteria and Key Discussion	Evaluation Results
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist practical application
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purposes
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	• Aerospace industry • Niche in sub-contract machinery components • ISO9002 qualified company
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality, delivery reliability, and cost
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• Advanced CNC (Computerised Numerical Control) machines and facilities • FMS (Flexible Manufacturing Systems) • SPC (Statistic Process Control) • FMEA (Failure Mode and Effectiveness Analysis)
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Contract maintenance, operator monitoring, and reactive maintenance
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Quality, capacity, maintainability and safety • Process is batch type and volume is project type
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	Simple maintenance by operators, on-condition maintenance and outsourcing of heavy maintenance
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	• Multiple skilled and well trained employees • Three shifts working facilities • CALS (Computer Aided Logistics Support) and ILS (Integrated Logistics Support) application • LCC (Life Cycle Cost)
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Delivery reliability • Quality • Flexibility • Cost and the performance measures and indicators in the developed framework provide lots of hints
Decision–Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	Non-financial performance measures can be important in particular measures and indicators related to quality and maintainability due to the high quality requirements in the aerospace industry
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Major facilities are rarely replaced but some of the facilities are enhanced capability. The decisions are made by the requirements of new technology development on CNC machine development • Maintenance is always the first priority
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Performance measures and indicators developed in PFM framework are acceptable • A total of 10-12 performance indicators are recommended
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has no strategy formulation process

6.5.8 Evaluation Results of the PFM Framework of Company F

The full results of the interview in company F are shown in the following table.

Table 6.11 Table of Evaluation Results for Company F

Evaluation Results for Company F	
Evaluation Criteria and Key Discussion	**Evaluation Results**
Feasibility (Practicality of using the PFM framework)	• The framework is reasonable and the implementation process is acceptable • "Strategically driven" concept is acceptable
Utility (Overall usefulness of the PFM framework)	• Developed PFM is most beneficial for new facilities assessment • Implementation Workbook can assist practical application
Propriety (Evaluation is carried out fairly)	The example test is acceptable and the background data are acceptable for test purposes
Product (group) and facilities and machine (group) analysis (Evaluating section one to section 18 of the PFM framework)	• Origina micro-chip disc manufacturer • ISO9002 qualified company
Most important competitive criteria (Evaluating section one to section 11 of the PFM framework)	Quality, delivery lead time, design flexibility, and cost
Facilities investment strategy (Evaluating section 10 to section 26 of the PFM framework)	• Advanced micro-chip manufacturing technology • FMS (Flexible Manufacturing Systems) • SPC (Statistic Process Control) • FMEA (Failure Mode and Effectiveness Analysis)
Type of maintenance management system (Evaluating section 9 of the PFM framework)	Contract maintenance, operator monitoring, and reactive maintenance
Facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Quality, capacity, maintainability and safety • Process is continuous type
Requirements of facilities management (Evaluating section 6 to section 10 of the PFM framework)	Simple maintenance by operators, on-condition maintenance and outsourcing of heavy maintenance
Facilities management policy (Evaluating section 6 to section 26 of the PFM framework)	• Multiple skilled and well trained employees • Three shifts working facilities
Key facilities performance measures (Evaluating section 15 to section 22 of the PFM framework)	• Delivery reliability and quality • Flexibility and cost • The performance measures and indicators in the developed framework provide lots of hints
Decision-Making influencing factors (Evaluating section 7 to section 22 of the PFM framework)	Non-financial performance measures can be important in particular measures and indicators related to quality and delivery led time due to the high quality and fast changing environment of the computer industry
Maintenance/Enhancement/Replacement Decisions (Evaluating section one to section 26 of the PFM framework)	• Major facilities are rarely replaced but some of the facilities are enhanced. The decisions are made by the requirements of new technology development on chip manufacturing technology • Maintenance is always the first priority
Recommended quantity of performance measures and indicators in monitoring facilities performance (Evaluating section 15 to section 22 of the PFM framework)	• Performance measures and indicators developed in PFM framework are acceptable • A total of 10-12 performance indicators are recommended
Formal manufacturing strategy formulation process (Evaluating section one to section 10 of the PFM framework)	Company has strategy formulation process with mission statement

6.5.9. Findings of the External Surveys

The findings from the results of the external tests are summarised as follows:

1. As a result of 161 selected companies for the postal survey, 12 respondents answered the questionnaire. In general, the postal survey had a very low response rate and the characteristics of non-respondents are unknown. However, the results of the postal survey still showed that the management of production facilities is one of the main activities for manufacturers. Compared to the postal survey, the face-to-face survey was more successful, and the six interviewed companies all recognised the framework of the PFM model as well-structured and theoretically applicable. The main contribution of implementation of the PFM process is that it can provide a helpful tool to identify the business strategic objectives and translate them into Production Facilities Management monitoring requirements, and enhance and support the analysis of the facilities life cycle and decision-making analysis.

2. The strengths of the PFM framework:

- The interviewees agreed that the management of production facilities should be linked with the strategic requirements which indicates the subject of the research is significant in pragmatic application. The PFM framework implementation workbook provides a useful aid in training and implementation of a PFM plan. However, the policy of the company cannot permit them to use the PFM framework directly. The interviewees agreed that the structure of the PFM implementation process is reasonable after all.
- The manufacturing strategy formulation process provides a standard procedure to capture the strategic objectives which is very useful to establish a company-wide consensus of the PFM.
- The development of the PFM Performance Measurement System (PMS) helps in establishing a facilities performance monitoring and improvement plan.
- The competitive criteria, performance measures and performance indicators matrix table has provided useful information for the company to assess the performance both

business and facilities. Almost all of the interviewed companies do not have a performance measurement system. Very few parameters were being used at the moment.

3. The weaknesses of the PFM framework:

- The implementation process is too long which will inhibit the implementation and training in reality. The recommended improvement is to divide the implementation process into several stages and sections and increase signposts in the whole process.
- All of the Performance Measures (P.M.) and Performance Indicators (P.I.) are significant to the PFM. However, the implementation of the PFM process will become too complicated to analyse if all of these data are involved. The recommended improvement is to simplify the performance monitoring process. There is a need for identifying the most important P.M. and P.I. to monitor the performance in a practical application. After the interview survey, it was recommended that the preferable number of these P.M. and P.I. is between 10 to 12 items.

4. The application of the Utility Value calculation is accepted by the interviewed companies to be treated as a workable tool in solving the complicated decision-making process. Also the application of Analytic Hierarchy Process (AHP) theory and the Expert Choice software which is developed on the AHP theory are all helpful in the Multiple Criteria Decision-Making (MCDM) process. The decision-making analysis process becomes more complicated after mixing the qualitative and quantitative factors in reality, however it can be solved by the utilisation of the weight of importance of each criterion and the application of the aforementioned methodologies.

5. To most of the companies, maintaining the existing facilities is always the first priority amongst the three options of the management of facilities, i.e. maintaining, enhancing or replacing them. Even though the interviewed companies realised the importance of total maintenance cost as one of the areas that could be improved and costs saved from it, the maintenance of current facilities has not been carried out in the way that it should have. Nevertheless, in the management field, there are many theories that are continually being developing such as CMMS, TPM, RCM, ILS, CALS and BCM. The

overall result of the survey highlights that there is still a need for more communication between academic research and practical operation in PFM.

6. Almost all of the interviewed companies recognise the importance of prioritising these competitive criteria. The priority of them will influence the trade-off in many decision-making situations, direction of the company, the execution of these strategic requirements, and PFM. In this survey, their importance is distributed from the most important to the least important as Quality (Q), Cost (C), Delivery Reliability (DR), Price (P), Delivery Lead Time (DLT), Speed (S), Volume Flexibility (VF), Design Flexibility (DF), and Service (S). In general, the priority of these criteria is reasonable and can be applied in the decision-making analysis of the PFM model for the priority of strategic requirement. However, it is still based on the unique decision of the company, i.e. the niche field of the product and manufacturing environment will influence the priority of these criteria.

7. Preventive maintenance at fixed intervals and corrective maintenance are the most common maintenance techniques in facilities management. Most of the companies have not fully made maintenance a company-wide issue. In large firms, centralised maintenance centre dominates resources which are distributed in discrete buildings in e.g. Company A, but outsourcing has become important in small firms with centralised maintenance department to dominate maintenance resources, e.g. Company E.

8. From the results of the interview surveys, it is seen that the majority of the interviewed companies do not have a formal strategy formulation process which shows that in the manufacturing industry there is still the lack of a link between manufacturing functions and strategy. As Skinner (1996) argued, the use of manufacturing in corporate strategy as a management practice is still not widespread enough after his first announcement in 1969.

9. The comparison between eastern and western management philosophy. The eastern is much more focused on human resource management which believes the training and management of the operators will reduce facilities breakdown whilst the western is focused on system establishment.

10. The usage of quick hit tables in the developed PFM implementation workbook provides a considerable contribution to the references in decision making. It is suggested that these items be reviewed periodically so as to keep them up-to-date.

11. From the viewpoint of TQM (Total Quality Management), the improvement of performance should be executed continuously. The stage of the improvement action in section 26 is not the last section of the improvement programme. It is recommended that the step after the 1st stage improvement action in section 26 is to return to section 11 as a loop when improvement is deemed to be necessary.

12. The interview was time-consuming but it was a flexible and adaptable way of finding things out. Face-to-face interviews offer the possibility of modifying the structure of the PFM framework in a way that postal questionnaires can not.

6.6 Conclusions

The results from the questionnaire surveys and interview surveys formed the basis for drawing the conclusions from the evaluation programme. The main findings and a discussion of the feasibility, utility and propriety from the interview surveys have been highlighted in section 6.5 of this chapter. This section concludes the main findings from the evaluation test programme. They are described as follows:

1. The results of the internal and external tests shows that a gap does actually exist in the application of manufacturing strategy in production facilities management between academic research and pragmatic implementation. Compare the results of the external tests with Hayes *et al* (1984) who stated that the capacity / facilities decision process should be strategically-driven, and it is seen that there is still lack of a tool to assist the implementation of this concept in reality. However, the PFM framework has provided such a solution to address the problem and the interviewees found that the PFM framework is useful. The PFM framework has implemented the strategically-driven concept into facilities management.

2. The benchmarking of the performance of the business and operation is a vital factor to be competitive for the manufacturing industry. Without an understanding of the existing performance, the company cannot improve their competitiveness. From the literature review, several benchmarking techniques and parameters have been recommended (see chapter 2) but from the results of external tests, it is seen that there is still a gap between the academic research and practical application of them. The PFM framework has provided an initiative for the manufacturers to establish a performance measurement system to monitor the performance of business and facilities. The concept of a hierarchical performance measurement system in the PFM framework regulates the strategic requirements and performance standard in different levels of the organisation.

3. From the results of external tests, the interviewed companies agreed that the PFM framework provides a tool for monitoring the performance of existing facilities, and a tool for the decision making support analysis. The analysis of the historic operational data (mainly from the collection of the historic maintenance data) with the linkage to the strategic objectives will assist the company to make a compromised decision in investment of the facilities.

4. Although the interviewees of the external tests agreed that the PFM framework is well structured and reasonable from their viewpoint of management for the practical application of the PFM framework. There was an issue during the evaluation process of the PFM framework which is that the companies cannot accept to implement this framework in their companies at the moment. Because there is no contract between the interviewer and the interviewees and the interviewed companies did not have the exact historic operational data which could be used for the evaluation. The lack of practical operational data from the manufacturers was a problem that cannot be solved within the evaluation programme. However, these interviewees agreed that the strategic-driven PFM framework, the performance measurement system, the performance parameters and the data of the example test have provided them with an initiative to implement production facilities management with strategic objectives. The results of the evaluation programme suggested that once the PFM framework can be

implemented in the company then it would increase the efficiency and effectiveness of production facilities management and the competitiveness of the company in the future.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This chapter concludes the research presented in this thesis. It describes and discusses what has been studied, how it has progressed and what has been achieved (issues, objectives, approach and solutions). This chapter also evaluates the main findings together with a discussion of the strengths and weaknesses of the research. Further research recommendations that could continue the work of this programme are also outlined.

7.2 Research Aim and Objectives of the Programme

The aim of the research was defined in chapter 3:

"*To develop, test and refine a strategically driven Production Facilities Management (PFM) framework to support the manufacturing strategy and develop a step-by-step implementation process by exploring the academic theories and industrial practices.*"

The research aim was addressed by completing a set of objectives. These objectives were as follows:

1) Identify the gaps between theoretical approaches and pragmatic practices in relation to PFM. Discuss the strengths and weaknesses of these theories and practices.
2) Identify the requirements for a new method of strategically driven PFM framework so as to capture the strategic requirements of the business and consequentially transform them into objectives of PFM.
3) Develop a step-by-step implementation workbook for the application in reality. The method is developed to apply the strengths of the academic approaches. Then evaluate the method and identify the results that the research indicates.

7.3 Discussion Against Research Objectives

Based on the aim and objectives of the research, an implementation programme was established (see chapter 3). The results of the implementation of the research programme are concluded along with the completion of the aim and objectives.

Objective one: Identify the gaps between theoretical approaches and pragmatic practices in relation to PFM. Discuss the strengths and weaknesses of these theories and practices.

To accomplish the first objective, several areas in relation to PFM have been reviewed and compared (see chapter 2). The main reviewed areas include the manufacturing strategy formulation process, current production facilities maintenance practices and theories (e.g. TPM, RCM, BCM, and CMMS), life cycle management practices and theories (e.g. ILS, CALS, Terotechnology, and WCM), performance measurement system requirements and design, decision-making techniques (e.g. AHP and UV application), and benchmark techniques (e.g. QFD, Balanced scorecard, polar diagram, Deming, Baldrige, and EQA). From the literature, the key issue is that all of these theories and techniques are related to PFM, however, they have strengths and weaknesses themselves (see chapter 2) but without an appropriate means to integrate the strengths. All in all, results from the literature identify the key issues in relation to PFM (see conclusion of chapter 2) as:

1) The lack of a formal manufacturing strategy process to cope with the continuously changing environment
2) The lack of linkage between the facilities management and strategic requirements
3) The lack of flexible (for efficiency) and reliable (for effectiveness) manufacturing facilities to ensure the competitiveness of the manufacturing function
4) The need for a performance measurement system to assist the production facilities life cycle prediction and management

In order to understand the difference between the academic research and practical application of the manufacturing industry in reality, a questionnaire survey was accomplished (see chapter 6). Results from the questionnaire survey also identified that many academic theories related to PFM were not known or applied by the manufacturers in reality (see chapter 6). These reviewed and surveyed results (see chapter 2 and chapter 6) concluded that there was room for improvement in integration of strategic requirements, performance measurement and maintenance management to predict the life cycle of a production facility and make appropriate decisions on PFM (see chapter 4).

Objective 2: Identify the requirements for a new method of strategically driven PFM framework so as to capture the strategic requirements of the business and consequentially transform them into objectives of PFM.

Even though it was highlighted by Hayes (1984) and Kelly (1997 and 1998) that capacity and facilities management should be related to the strategy of the business, very few publications were found that relate to the linkage between strategy and facilities management and detailed implementation procedure for this linkage. Based on the results of the literature, the realisation of the proposed approach tries to conciliate the gaps between theories and practices and an implementation programme was established (see chapter 3).

The key items that were achieved throughout the research programme include (see chapter 3):

1) Exploratory collection of related methodologies and techniques by literature review, conference participation, exhibition and company visiting.
2) Explanatory analysis of the strengths and weaknesses of the collected methodologies and techniques, explanation of the weakness and new insights and application of the strengths.
3) Evaluation of the PFM framework using internal review and test, questionnaire postal survey and face-to-face interview.

To develop the new method of strategically driven PFM, the following were identified to be the specifications of PFM model development (see chapter 4):

1) Coherent with the corporate and operational strategies
2) Adequate measurement of the operation and implementation process
3) Adequate control of the facilities performance monitoring and improvement
4) Adequate assessment methodologies and technique application

Objectives 3: Develop a step-by-step implementation workbook for the application in reality. The method is developed to apply the strengths of the academic approaches. Evaluate the method.

Based on the specifications, questionnaire surveyed results and reviewed literature, a strategically driven PFM framework and conceptual implementation model was accomplished (see chapter 4). After internal tests of the feasibility and utility of the conceptual model, the conceptual model was discussed within an international conference of production research in Ireland (as conference paper in Appendix M). A more detailed implementation process was developed consequentially after the conceptual model was established (see chapter 5). For the aid of practical application, a detailed step-by-step implementation workbook was also accomplished and documented as the outcome of the research (as Appendix D). As the purpose of the test of the feasibility utility and propriety of the implementation framework and implementation workbook, a series of surveys and tests were undertaken (chapter 6). In the end, the developed PFM framework was evaluated to provide a considerable contribution in narrowing the gaps identified in the literature review stage (chapter 6).

7.4 Strengths and Weaknesses of the Research

There are a number of strengths and weaknesses of the research programme. These are as follows:

Strengths of the research

- ***Learn through the research process of the application of academic concepts into practical applications in reality*** – Several academic theories and techniques were reviewed and used in the PFM framework which narrows the gaps between academic research and practical application in the manufacturing industry.

- ***Modify traditional production facilities management by maintenance management into strategically driven facilities management*** - As stated in chapter two, the traditional concept of PFM is focused on the maintenance field only. However, maintenance management is the most important basis for the development of a PFM framework due to almost all of the operational data being collected by the maintenance information management system. More and more researchers have announced that the savings from maintenance are alternative profits to any manufacturer. Effective strategies deliver plant reliability and good maintenance emphasises the need to consider plant reliability within a wider context of corporate and production objectives (Bates, 1996, and Kelly, 1997, 1998). The capacity/facilities management should be integrated into strategy (Hayes, 1984).

- ***Integrate the performance assessment requirements of the different levels of the company and build up the consensus of the PFM*** – The establishment of the PFM Performance Measurement System (PFM PMS) integrates the requirements of different levels of the company. The strategic requirements of the corporate level are shown in terms of competitive criteria such as, quality, delivery reliability, delivery lead time, design flexibility, volume flexibility and cost. The requirement of the operational level is shown in terms of the performance measures of the facilities such as MTTR, MTBM, Breakdown Frequency, etc. The hierarchy of the PFM PMS standardises the performance monitoring and control process.

- ***A detailed implementation workbook helps the personnel to implement a standardised PFM process*** - The development of the PFM implementation workbook provides the personnel of the company with a step-by-step standardised procedure to implement PFM work.

The weakness of the research is the arrangement of the evaluation programme. The implementation of an evaluation process is a time-consuming task. The most difficult part is the support from resources outside the university. As a result of the questionnaire survey, the ratio of the respondents was 8% and only 4% of the companies would accept interviews. None of the interviewed companies were willing to implement the PFM framework into their system of organisation. There are two recommendations to improve similar situations for the research in the future:

- ***Increase the communication of the candidate companies before and after the questionnaire survey*** – In preparing the candidate companies, the willingness of specific personnel and the company to answer the questionnaire should be confirmed. After the questionnaire was issued, an effort at hastening the return of the questionnaire and communication with the respondents is important.

- ***Design and implement the evaluation programme as early as possible*** – The evaluation of the feasibility and utility of the PFM framework is essential for its contribution to the whole research. From the results of the questionnaire and interview surveys, it rarely happened that the companies had the exact data to supply or they are willing to apply the PFM framework directly to their existing system. However, almost all of the interviewees had a strong willingness to discuss the innovation of the PFM framework. Therefore, it is recommended to design and implement the evaluation programme as early as possible.

7.5 Contribution to Knowledge

This research has made two main contributions. These are:

(i) ***Review of existing methods and industry, highlighting their strengths and weaknesses in relation to production facilities management***

Through literature review and questionnaire surveys, the strengths and weaknesses of the existing methods related to PFM were highlighted and the usage of these methods by the present manufacturers was analysed. The results of the review indicate that the linkage of the facilities management with the strategic objectives is essential to improve the competitiveness of the company.

(ii) ***Integration of the strengths from existing theories and methods and from the industry to develop a new approach of strategically driven PFM framework***

The PFM framework is used to monitor the performance of existing facilities and assist the decisions to be made under the consideration of strategic requirements. The contribution to knowledge is the development of logic for a strategically driven facilities performance assessment process. The development of a PFM implementation workbook provides a systematic step-by-step implementation tool to assist the achievement of PFM. The contribution to knowledge also includes the collection of the available measures and indicators for monitoring the performance of the production facilities from existing methods and techniques such as TPM, RCM, ILS, and CALS.

7.6 Limitations of the Research

The development of the strategically driven PFM framework is based on the literature and information acquired from various companies in the manufacturing sector. As in any research, the more cases for the tests of the developed solution the more precise the conclusion will be. However, there is difficulty in asking the invited companies to provide the operational data of their facilities for the test work due to a number of reasons. They are (see chapter 6):

1) Company regards operational and facilities capacity as being confidential data due to the nature of competition
2) Company does not have the willingness for the test due to policy
3) Company does not have such kind of Management Information System (MIS) to execute the information management work

Due to the lack of research in this specific subject area of strategically driven facilities management, the proposed solution is developed on programmes from work carried out in various areas of research (see chapter 2). However, the results achieved from the face-to-face survey within the research determine that the proposed solution should produce a valid contribution to knowledge and potential application in reality.

There are many theories, methodologies, techniques and tools related to PFM that could have been analysed, criticised and learned from. Because of the limitation of time available and resources, it is not feasible to identify all of them. However, the major ones have been reviewed. This means that the results obtained are based only on the information that could be collected and analysed.

Time and distance also proved to be one of the limitations. Due to the limitations of time and resources available, only a certain number of case studies (face-to-face surveys) could be carried out within the scope of this research (see chapter 6). Companies who were invited to take part in the evaluation test could only offer a limited amount of time to interview users. Some of the interviewed companies were even located in Taiwan. The evaluation work was limited by distance and communication. The positive results thus obtained have only demonstrated their usefulness in a practical sense. However, there is a great appreciation of the assistance that the limited interviews have contributed to the implementation of the evaluation test.

The aim of the research was to develop and evaluate a generic solution for implementing the production facilities management (PFM) process within the manufacturing industry. More specifically, the framework was evaluated so that it could be applied to the aircraft, automobile and component industries. However, since different industries have different environments, the framework is unlikely to be limited to these industries. It is the author's opinion that the framework has the potential to be applied to other industries, such as chemical industry, although it is suggested that more research be carried out to justify this argument.

7.7 Further Research Recommendations

During the literature survey, model development and evaluation stages, a number of areas have been identified where further research would increase the knowledge and understanding of the processes. Some of the areas where this scheme also provides a solid foundation would profit from further research. Proposals for future research areas are suggested below:

1. Using the strategically driven PFM implementation process and workbook as a basis for the integration of IT (Information Technology) evolution

From the literature survey to the questionnaire survey to the interview survey, it is obvious that a powerful means to solve the issue of the collection and analysis of a huge data bank of historic operational data is required. This highlights the importance that the PFM should be linked with the application of IT (Information Technology) which includes the integration of CMMS (Computerised Maintenance Management System), and MIS (Management Information System). For further research, the developed PFM implementation framework and workbook could be adopted as a basis for the further development of a software system in PFM. It is recommended that further development integrate the concept of EDI (Electronic Data Interchange) so as to standardise the background data and improve the performance assessment on a real-time and intranet basis.

2. Further surveys to condense the number of performance measures and performance indicators

There are a number of parameters involved in establishing the hierarchy of the performance measurement system. Also, there is a large amount of operational data involved in the assessment and analysis process. It is recommended that more surveys be undertaken so as to understand the deviation of these parameters for performance monitoring and control in different manufacturing sectors.

3. Further development of the integration of human factors into the PFM framework and enhancement of PFM framework into an expert diagnostic system

Even within an automated manufacturing system, the human skill and human-centred activities cannot be removed (Kahen, 1997 and Greenough, 1999). In a man-machine system, the human element will greatly influence the effectiveness and efficiency the results of practical implementation. How to integrate the human abilities into the PFM activity so as to ensure the performance of the PFM framework requires further development. The recommendations also include the usage of an expert system, multimedia and hypermedia to enhance the PFM framework into an expert diagnostic system.

7.8 Final Conclusions

This chapter has concluded the research programme by describing the progress accomplished towards the research aim and objectives. The contributions of the research have been identified and limitations have been addressed.

In facilities management, to improve the maintainability, reliability, availability and supportability of the production facility is the target for the facilities manager to fight for. From the questionnaire survey and face-to-face interviews, it is obvious that facilities management without a strategic focus is popular at present. The attitude of leaving production facilities management on 'run until it breaks down' is an old but practical situation in the production facilities management strategy. This happens both overseas and locally. However, this kind of management policy for PFM will create wasted costs in the end.

From the literature survey, it is seen that demands on the manufacturing industry to provide the right quality, high flexibility, short lead time, and to reduce total costs and unit price have put pressures on manufacturing companies. Different companies might have their own priority among these criteria. For decades, production and operations researchers have recognised these as the most important strategic criteria to meet.

The concept and techniques of "manufacturing strategy formulation" offer management the opportunity to use their production function as a weapon in competition. However, the manufacturing strategy always comes first for the success of a business.

The benefit of the PFM framework is that it can be used as a standardised approach in implementation of production facilities management.

The strategically driven PFM framework proposed and evaluated in this thesis is directed at improving the efficiency (doing the job right) and the effectiveness (doing the right job) of a production facility management to ensure the competitiveness of the corporation especially with the support of the manufacturing function. Understanding the performance and ability of the existing facilities with the strategic concerns will lead to improved performance of the corporation which in turn will make a sizeable contribution to profit growth in the end.

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Appendix A

The Self-assessment Benchmark Models

Introduction:

Increasing global competition has resulted in firms knowing that quality improvement will result in a reasonable return on investment. This situation forces many firms to seek guidelines to implementing a continuous quality improvement programme. Meanwhile, several national and regional quality self-assessment models have been developed so as to benchmark the performance of the implementation. Most of them are based on the concepts of Total Quality Management (TQM). The more popular ones amongst them are the Deming Application Prize, the Malcolm Baldrige National Quality Award, and the European Quality Award (EQA). The following sections will introduce these in terms of the model, application categories, self-assessment criteria and areas of examination.

A.1 The Deming Prize

The Deming Prize is the oldest self-assessment framework and was developed in Japan in 1951. There are ten criteria used for assessing the Deming Prize application and a complete list of critical factors distributed among the ten key areas is shown in Table B.1.

A.2 The Baldrige Award

The Baldrige Award is the abbreviation for the Malcolm Baldrige National Quality Award (MBNQA) which was established by US congress in 1987. The purpose is to raise awareness about quality and its importance for American organisations. A model shows the framework of the Baldrige Award Criteria in Figure A.1.

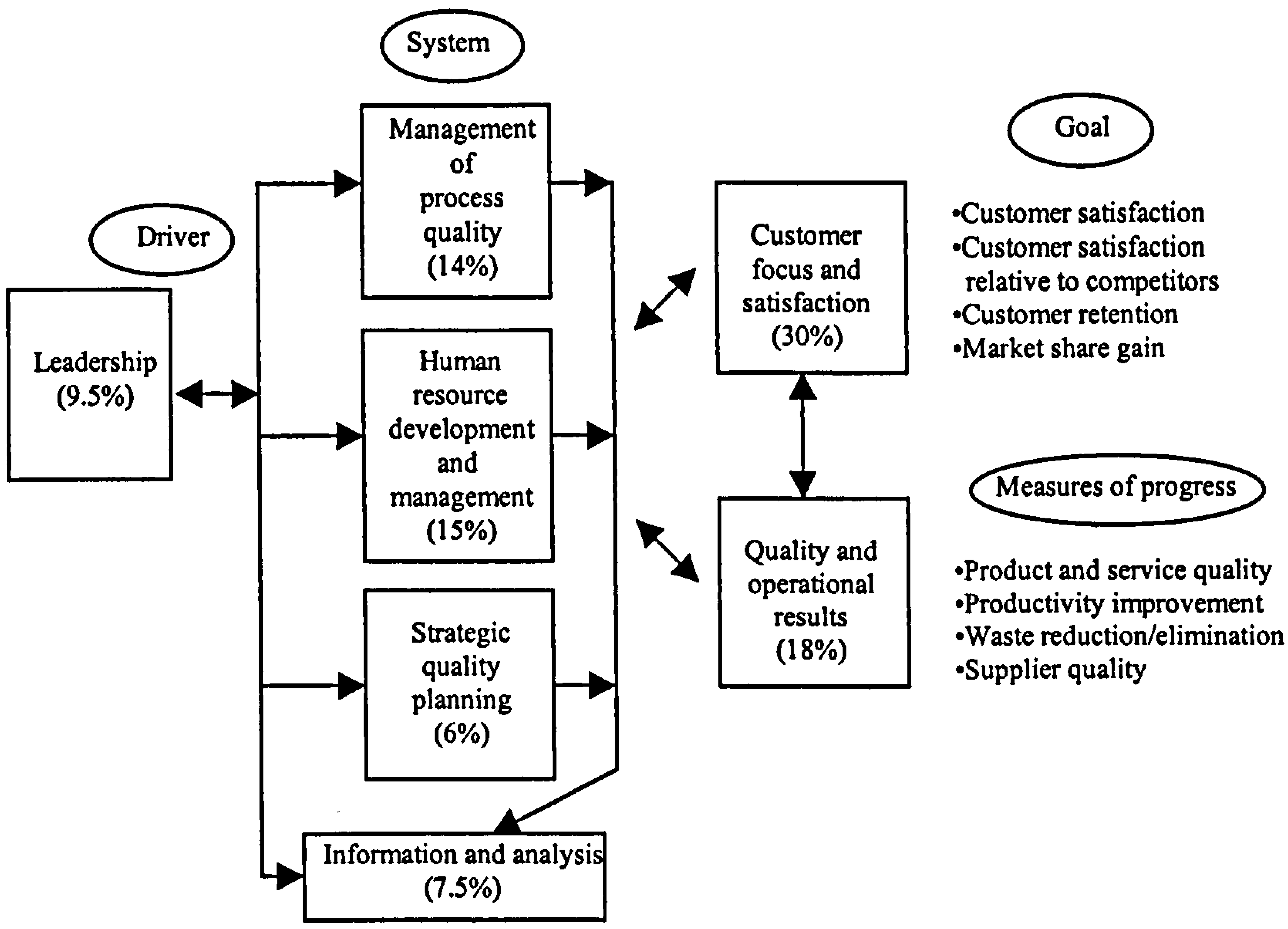


Figure A.1. Baldrige Award Criteria Framework
(Source: Nakhai et al., 1994)

A.3 The European Quality Award (EQA)

The EQA was developed and introduced by the European Foundation for Quality Management (EFQM) in 1991. The EFQM itself was created in 1988 by leading business organisations to alert European business organisations of the need to incorporate quality management in all operations and also to raise the level of knowledge and awareness of the benefits of TQM. There are twenty-eight critical factors covering seven key areas. A model shows the framework of the EQA in Figure A.2.

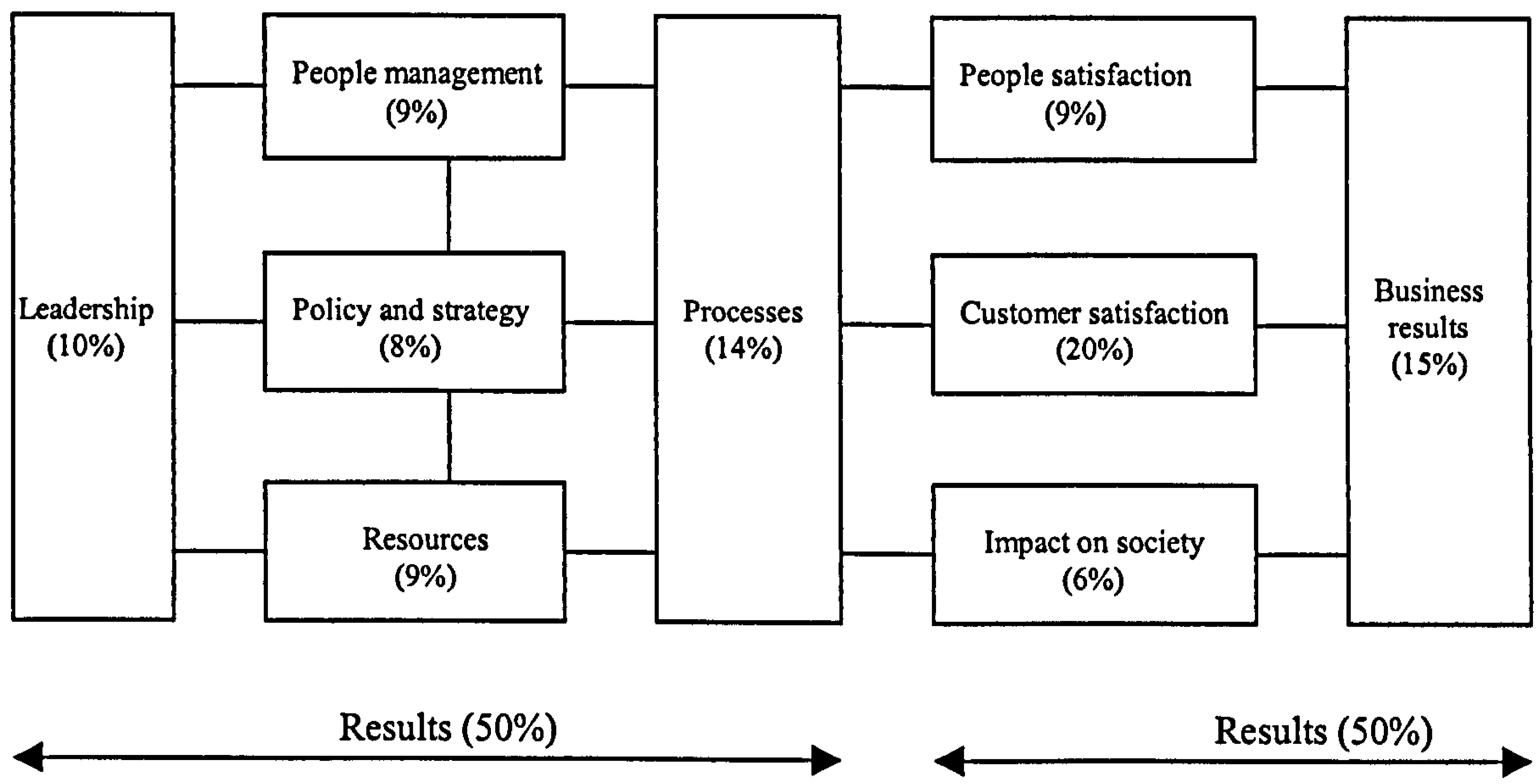


Figure A.2. The European Quality Award Model
(Source: Nakhai et al., 1994)

A.4. Comparison of The Deming, Baldrige, and EQA Criteria

A comparison of the criteria in each model is shown in Table A.1.

Table A.1 The Deming, Baldrige, and EQA Criteria Comparison Table

	Deming Prize	Baldrige Award	European Quality Award
Orientation	Established in 1951 in Japan	Established in 1987 by US congress in U.S.A	Established by EFQM (European Foundation for Quality Management) in 1991

	Deming Prize	Baldrige Award	European Quality Award
Key self-assessment criteria	1. Company policy and planning 2. Organisation and its management 3. Quality control education and disssemination 4. Collection, transmission, and utilisation of information on quality 5. Analysis 6. Standardisation 7. Control 8. Quality assurance 9. Effects 10. Future plans	1. Leadership 2. Information and analysis 3. Strategic quality planning 4. Human resource development and management 5. Management of process quality 6. Quality and operational results 7. Customer focus and satisfaction	1. Leadership 2. Policy and strategy 3. People management 4. Resources 5. Processes 6. Customer satisfaction 7. People satisfaction 8. Impact on society 9. Business results

Appendix B

Current Practices in Decision-Making Support Analysis

The decision-making process in PFM is complicated because it involves qualitative and quantitative measures and historic data. This contents of this Appendix B reviewed some current practices in Multiple Criteria Decision Making (MCDM) support analysis techniques which can be applied to the present PFM framework.

B.1 Utility Value (UV) Calculation

Utility Value is used as an analysis tool to assist the calculation of the relative weight of importance in multiple criteria of each criterion and gain an integrated value with respect to each other. The system utility can be considered to be a function of the product group importance, the importance of the competitive criteria for the individual product group and the performance of the individual product with respect to the competitive criteria (Hull, 1998). The system Utility Value is shown as:

$$U = Fn(I(\pi), N(\chi, \pi), \theta(\chi, \pi))$$

Where:

$I = Relative\ importance\ derived\ from\ manufacturing\ background$
$N = Market\ requirements$
$\theta = Manufacturing\ performance$
$\pi = Product\ group$
$\chi = Manufacturing\ competitive\ criterion$

Figure B.1. provides a simple description of how the Utility Value of product group and competitive criteria is formulated.

Competitive Criteria	Group A	Group B	Group C	Group D	Utility Values
Relative Importance	**Ia**	**Ib**	**Ic**	**Id**	
Quality	**Qa**				**U -Q**
Delivery Lead Time	**DLTa**				**U - DLT**
Delivery Reliability	**DRa**				**U - DR**
Design Flexibility	**DFa**				**U – DF**
Volume Flexibility	**Vfa**				**U – VF**
Cost	**Ca**				**U - C**
Product Group Utility Value Profile	**Pa**				**U - total**

Figure B.1 Product Groups and Competitive Criteria Utility Value Calculation *(Source: Hull, 1998)*

The competitive criteria Utility Value *Ux* can be written as:

$$U_x = \sum_{All\ Product\ Group} (Competitive\ criteria\ x\ Relative\ Importance)$$

For example, the total Utility Value of Quality criteria

$$Uq = Q_a x I_a + Q_b x I_b + \ldots\ldots etc$$

Where:

$Uq = Quality\ competitive\ criteria\ Utility\ Value$
$Q_a = Quality\ competitive\ criteria\ requirement\ for\ Product\ Group\ A$
$I_a = Relative\ impor\tan ce\ for\ Product\ Group\ A$
$P_a = The\ profile\ of\ Product\ Group\ A$

The UV application in PFM is to get the profile of the overall performance of each existing machine (group) with respect to each corporate competitive criterion. The overall performance of each machine (group) can be turned up in each criterion such as quality, delivery reliability, delivery lead time, design flexibility, volume flexibility and cost. The performance of each criterion can be divided into subordinate performance measures and indicators. The choice of the performance measures and indicators is decided by the organisation's strategy review board. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirement. This result also provides an assessment for the second stage's requirement of the improvement plan.

B.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a decision-making aid tool for dealing with complex, unstructured and multiple attribute decisions. It was developed during the 1970s by Prof. Thomas L. Saaty. There are three basic steps in using AHP:

1. ***Step 1: The description of a complex decision problem as a hierarchy – distinguishing the unstructured decision into components and then arranging them in a hierarchical order.***

In a typical hierarchy, the top level reflects the overall objective of the decision problem. This formulation process is very strategy-oriented. The elements affecting the decision are called criteria and they are represented at the intermediate levels. Criteria can be subjective or objective depending on the means in evaluating the contribution of the elements below them in the hierarchy. Criteria are mutually exclusive and their priority or importance does not depend on the elements below them in the hierarchy. The lowest level comprise the decision options or alternatives. The number of criteria or alternatives should be reasonably small to allow consistent pair-wise comparisons. A hierarchy can be divided into several sub-hierarchies sharing only a common topmost element.

2. ***Step 2: The prioritisation procedure- determining the relative weight of importance of the elements in each level.*** Elements in each level are compared pair-wise with respect to their importance to an element in the next higher level and starting at the top of the hierarchy and working down. A number of square matrices called preference matrices are created in the process of comparing elements at a given level. The decision maker can express a preference between every two elements verbally as equally important, moderately more important, strongly more important, very strongly important, or extremely strongly important. These descriptive preference are then translated into numerical ratings such as 1, 3, 5, 7 and 9. The nominal scale used in AHP enables the decision makers to incorporate experience and knowledge in an intuitive and natural way.

3. ***Step 3: The calculations of results – Deriving relative weight of importance for the various elements.*** The relative weight of the elements of each level with respect to an element in the next higher level are computed as the components of the normalised eigenvector associated with the largest eigenvalue of their comparison matrix. The composite weight of the decision alternatives are then determined by aggregating the weights throughout the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weight along each segment of the path. The outcome of this aggregation is a normalised vector of the overall weight of the options.

An example of the application of AHP in PFM is shown in the following Figure.

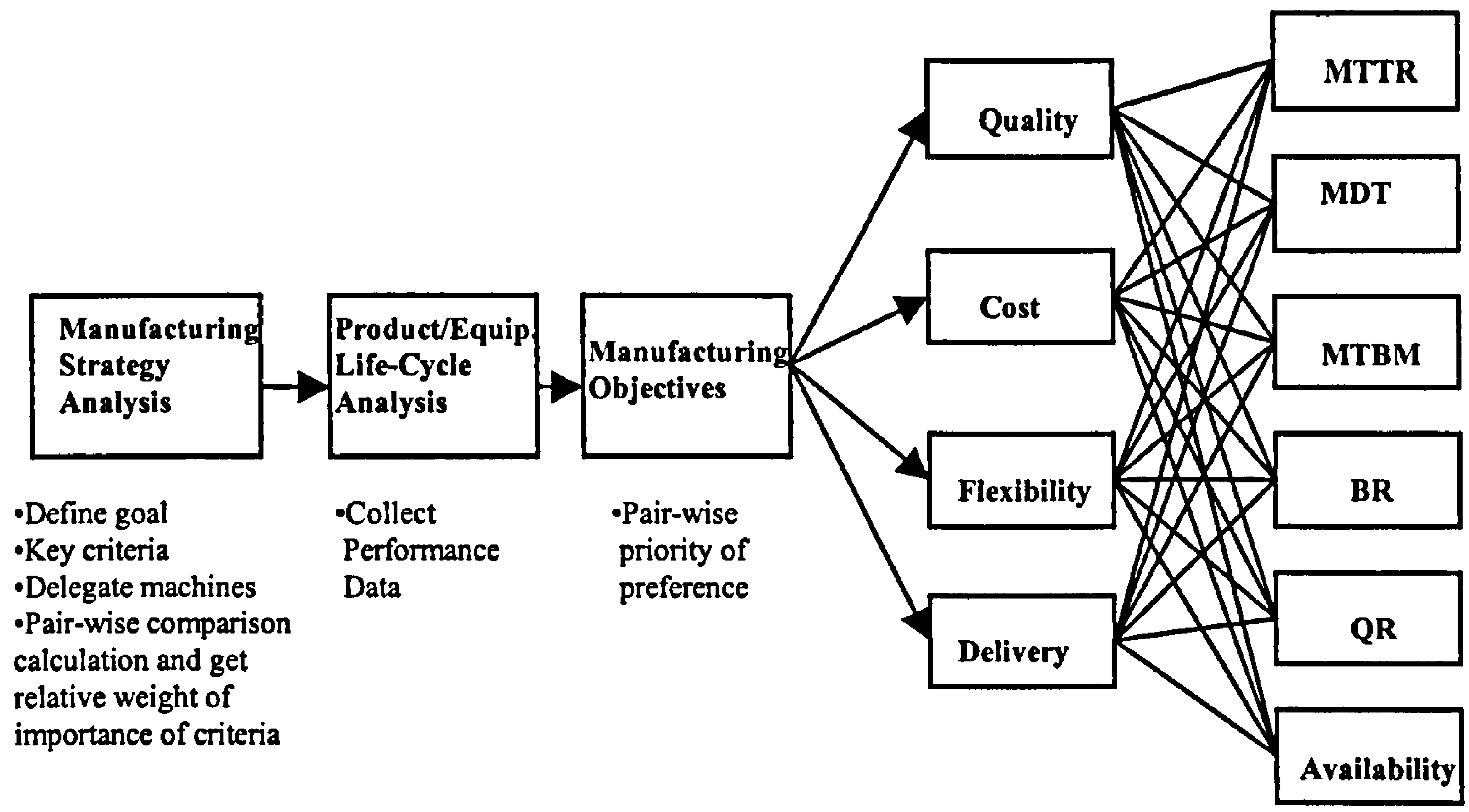


Figure B.2 AHP Application Example on Decision-Making Assessment of Replacing Existing Facilities

In practice, however, the use of AHP to model and analyse production decisions can be made much easier by using personal computer software, such as Export Choice. This software is very user-friendly and can greatly facilitate the user of AHP in the workplace.

B.3 Weibull Analysis

Weibull analysis is a technique used to assess the reliability of failure data. The items to be monitored and applied are reliability, hazard rate and failure distributions (Logothetis, 1992).

Reliability is a measure of the ability of a product to function successfully, when required, for the period required, under specified operating conditions. It is usually expressed as a mathematical probability, and so can lie between 0 or 0% (completely unreliable) and 1 or 100% (perfectly reliable). The failure percentage is (100-R) where 'R" is the percentage reliability.

If we consider failures in a population of items, the time to failure will have some distribution. We can then quantify the reliability of failure percentag at any desired age by estimating this failure distribution using data from a sample.

The failure distribution is characterised by a measure called the hazard rate, defined by:

$$HR = Rate\ at\ which\ remaining\ items\ fail$$
$$= \frac{Number\ of\ units\ failing\ in\ a\ time\ interval}{(Number\ of\ survivors\ at\ start\ of\ interval)\ x\ (Length\ of\ time\ interval)}$$

There are three types of hazard rate (Logothetis, 1992):

1. *Decreasing - infant mortality*: early failures resulting from construction errors.

2. *Constant – useful life / prime life*: random failures resulting from misuse by customer, occasional operating stress exceeding designed strength, etc.

3. *Increasing – wearout failures* due to wear, fatigue, chemical ageing such as corrosion, etc.

Items can experience one, two or all three of the above types. The Weibull distribution (as shown in Figure B.3) can be used to model failure modes from any of the three types of "*HR*".

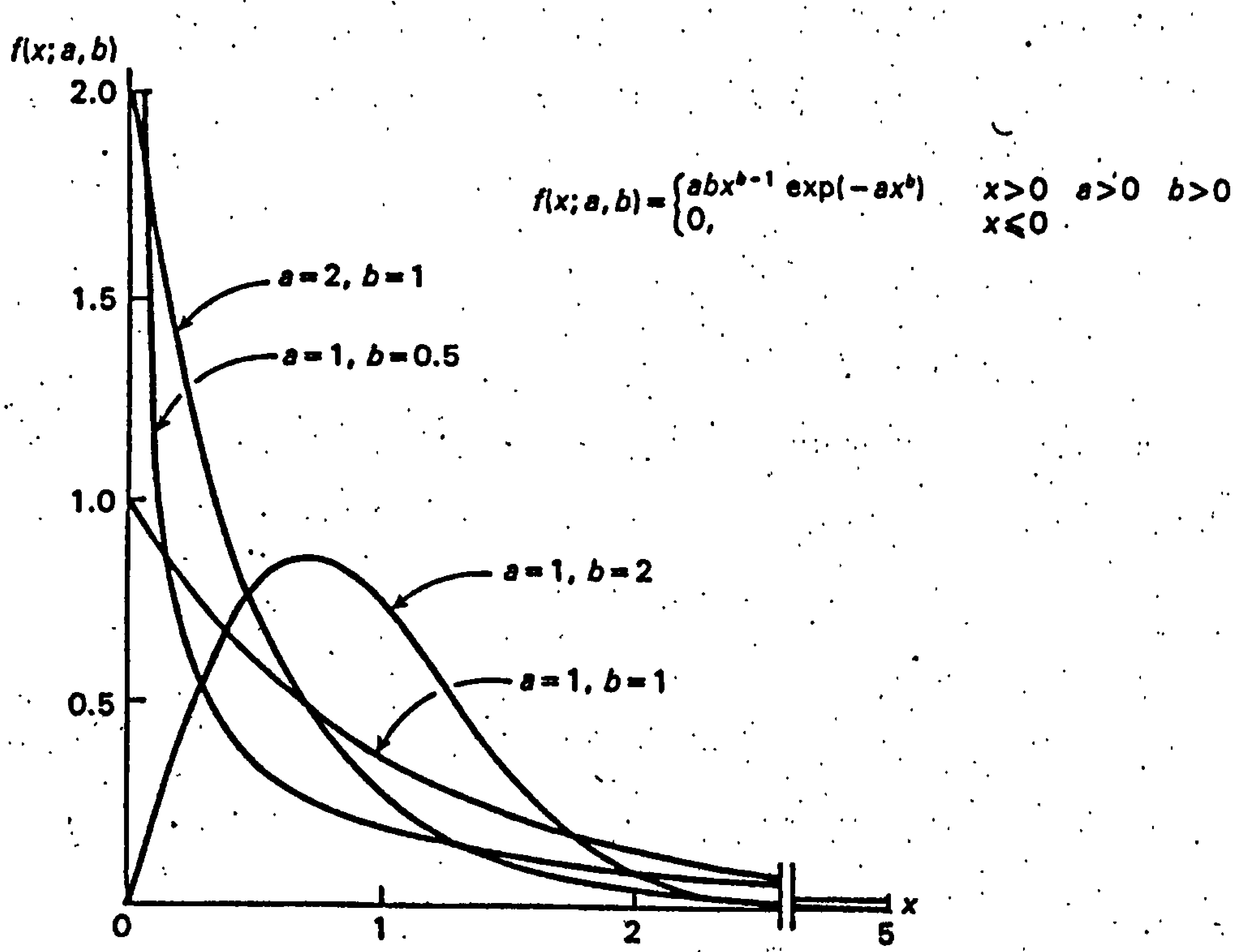


Figure B.3 Weibull Distribution Chart

(Source: Logothetis, 1992)

In its simplest form it moves two parameters:

β = *the slope or shape parameters*
α = *the scale parameter*
and the value $\eta = \dfrac{1}{\alpha}$ *is usually called the " characteristic life "*
Mathematically, this value represents the age by which 63.8% of the items under consideration fail. The Weibull application in PFM is based on the calculation that the variation of the shape parameter allows the modeling of the life distribution of items (for example: a facility) which follow any of the three types of "*HR*". In fact:

In the early life of a facility : *Shape* (β) < 1 , *where* " *HR* " *is decreasing*
In the useful life of a facility : *Shape* (β) $= 1$, *where* " *HR* " *is constant*
In the wear out stage of a facility : *Shape* (β) > 1 , *where* " *HR* " *is increasing*
When $\beta = 1$, *the exponential distribution is obtained , which is a special case of the Weibull distribution.*

So, the exponential distribution is characteristic of a constant hazard rate. It is useful for describing the life of a certain facility, and also for describing failures (due to any mode) of complex assemblies which are repaired, in which case, the characteristic life represents the (constant) Mean Time Between Failure (MTBF) for repairable systems, and Mean Time To Failure (MTTF) for non-repairable systems.

When the slope or shape parameter is larger than "5", the Weibull distribution is characterised by an increasing "Hazard Rate" and is useful for certain wear out processes (such as corrosion) and for describing in general the breaking strength of materials (in building codes, aircraft, etc.)

B.4 Quality Function Deployment (QFD)

QFD was first proposed and used in 1972 by Mitsubishi Heavy Industry's Kobe Shipyards site. Toyota and its suppliers then developed it in numerous ways. It is a kind of conceptual map that provides the means for inter-functional planning and communication. Its important characteristics are its (Hauser & Clausing, 1988):

1. Focus on customer requirements.
2. Use of multidisciplinary teamwork.
3. Dynamic conceptual map called the "House of Quality" used to document information and decisions, and aid communication.

The majority of the literature relating to the use of QFD focuses on further developments of the technique for its initial application in product design. It brings together the essential elements and characteristics of the various phases in the life cycle of a product. Implementing the QFD into PFM, it is used as a tool to help the recognition of the interrelationships between the engineering properties of the product and the customer's requirement, so that the customer needs are anticipated, prioritised and effectively incorporated into the product. Also, the same technique can be manipulated into the description of the interrelationships between the facilities performance monitoring and the corporate strategic requirements because the customer's requirements are compatible with the strategic objectives.

Its versatility and characteristic advantages though have led to its consideration for tackling other areas of the business development process. Crowe and Chao-Chun (1995) highlight QFD as an excellent mechanism for integrating manufacturing strategic planning with the company's overall business plan. QFD is proven to be a powerful tool to develop and resolve corporate strategic issues.

The basic procedure to follow is the construction of the house of quality.

1. *Step 1: Identifying customer requirements and major related concerns.*

   The construction of the house of quality starts with the identification of the customer's requirements known as the customer attributes (CA), which are listed on the left-hand side of the house. The typical CA are Quality, Delivery Lead Time, Delivery Reliability, Design Flexibility, Volume Flexibility, Cost, Price. These items describe customer requirements and major areas of concerns. Next to the CA are their relative importance (in numerical terms), as perceived by the customer. This information can be obtained through a market survey.

2. *Step 2: Evaluation of the performance of own company and competitors.*

   On the right-hand side of the house, a list is constructed of customer evaluations of how the performance of PFM stands relative to the competitors. In this way, improvement opportunities can be identified. This representation is assessed perceptually and it provides a comparative assessment in relation to the performance of the other competitors.

3. *Step 3: The facilities are then described in terms of their Performance Characteristic.*

4. *Step 4: The main body of the house of quality is now filled with the historic data.*

   Based on experience or previous statistical studies, a completed relationship matrix shows how much the performance of facilities will affect the customer-perceived quality.

On the whole, QFD is very effective for determining opportunities for improvement to satisfy the customer requirements. The house of quality is a summary of data that can serve as a permanent and complete record of all of the relevant information, enhanced to provide a solid and valuable initiative for further improvement (Logothetis, 1992). Based on the aforementioned QFD procedures, the following figure (B.4) shows the matrix of House of Quality applied on the PFM implementation for the analysis of the relationship between corporate strategic objectives and the performance of facilities.

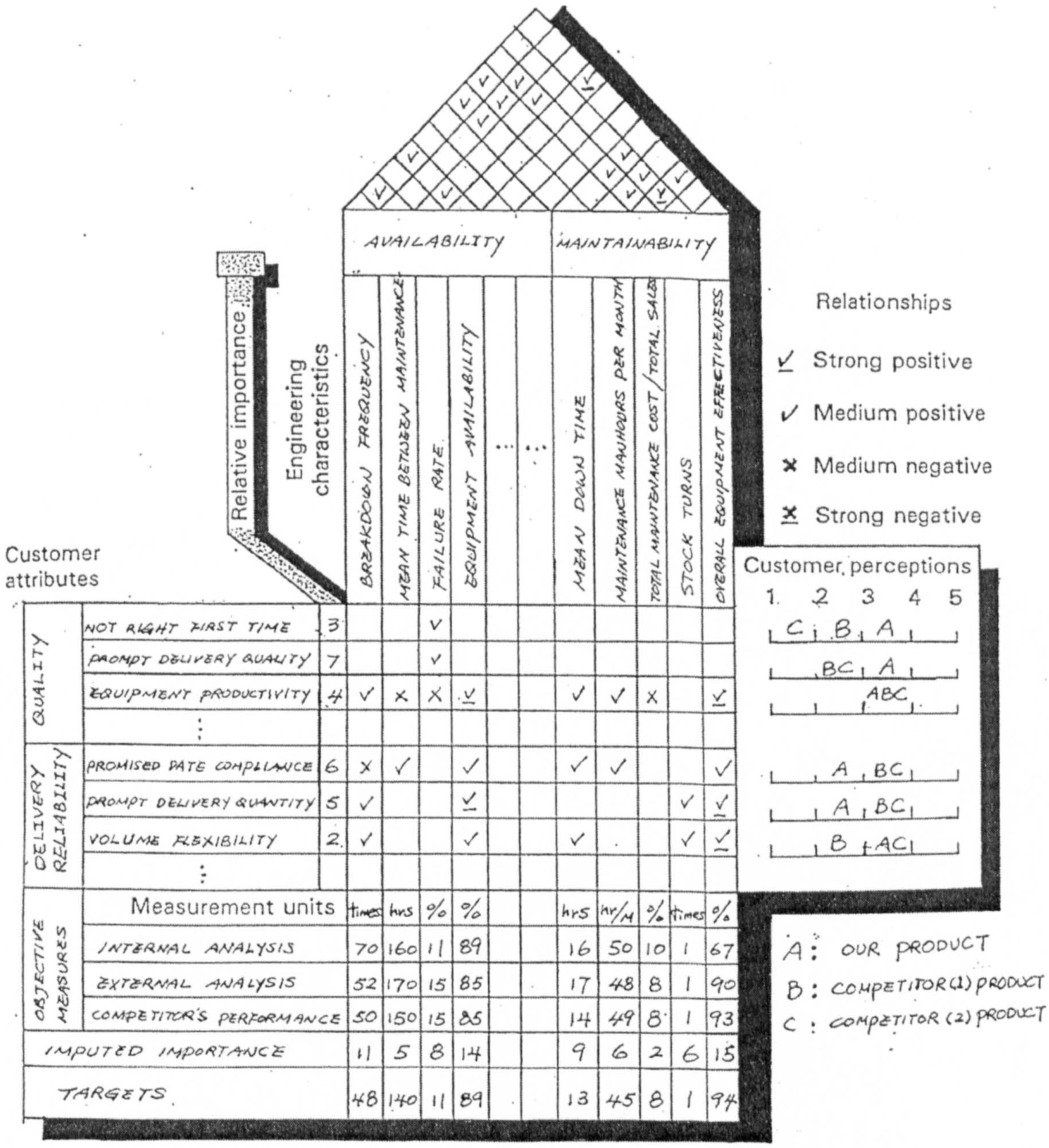


Figure B.4 House of Quality in PFM Implementation

Appendix C

Example Test of PFM Implementation Model with Combination of AHP (Analytic Hierarchy Process) Methodology Application

C.1 Introduction

The AHP theory was developed by Saaty in the early 1970s. The benefit of it is that it provides a logical framework to solve the difficulty in determining the priority ranking of alternatives involved in MCDM (Multiple Criteria Decision Making).

The example introduced here is to test the feasibility of the developed PFM conceptual model with the application of the software called "Expert Choice" which was developed by Expert Choice Inc, USA. The development of "Expert Choice" is based on the theories of AHP and helps in solving the complicated pair-wise calculation issue.

C.2 Test Process

The example test process is compatible with the conceptual PFM implementation model as shown in Figure 4.13.

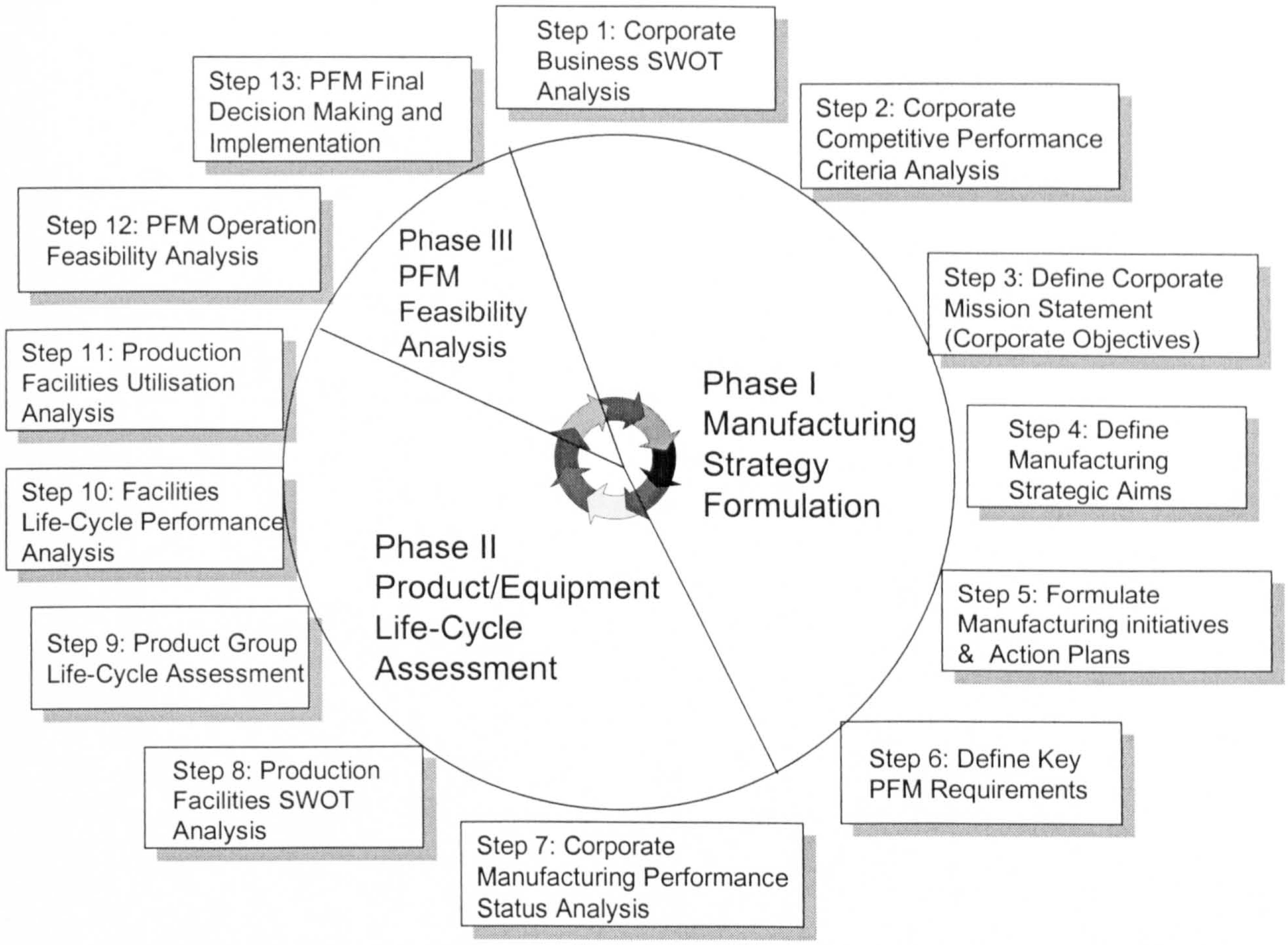


Figure 4.13 Conceptual Production Facilities Management (PFM) Implementation Model

This example test process demonstrates the process especially to establish the structure of a PFM performance monitoring system. The test process is implemented as follows:

1. ***Step 1: Define the goal, key criteria (PM/PI) and compare the relative "PREFERENCE" with respect to the goal.*** The key point is that the relative "PREFERENCE' of each criterion is decided based on the corporate strategic objectives and business focus (general success areas). Step 1 is accomplished with the establishment of a hierarchical structure of the performance measurement system as shown in Figure C.1. The test result is shown in Example 1 of Appendix C.

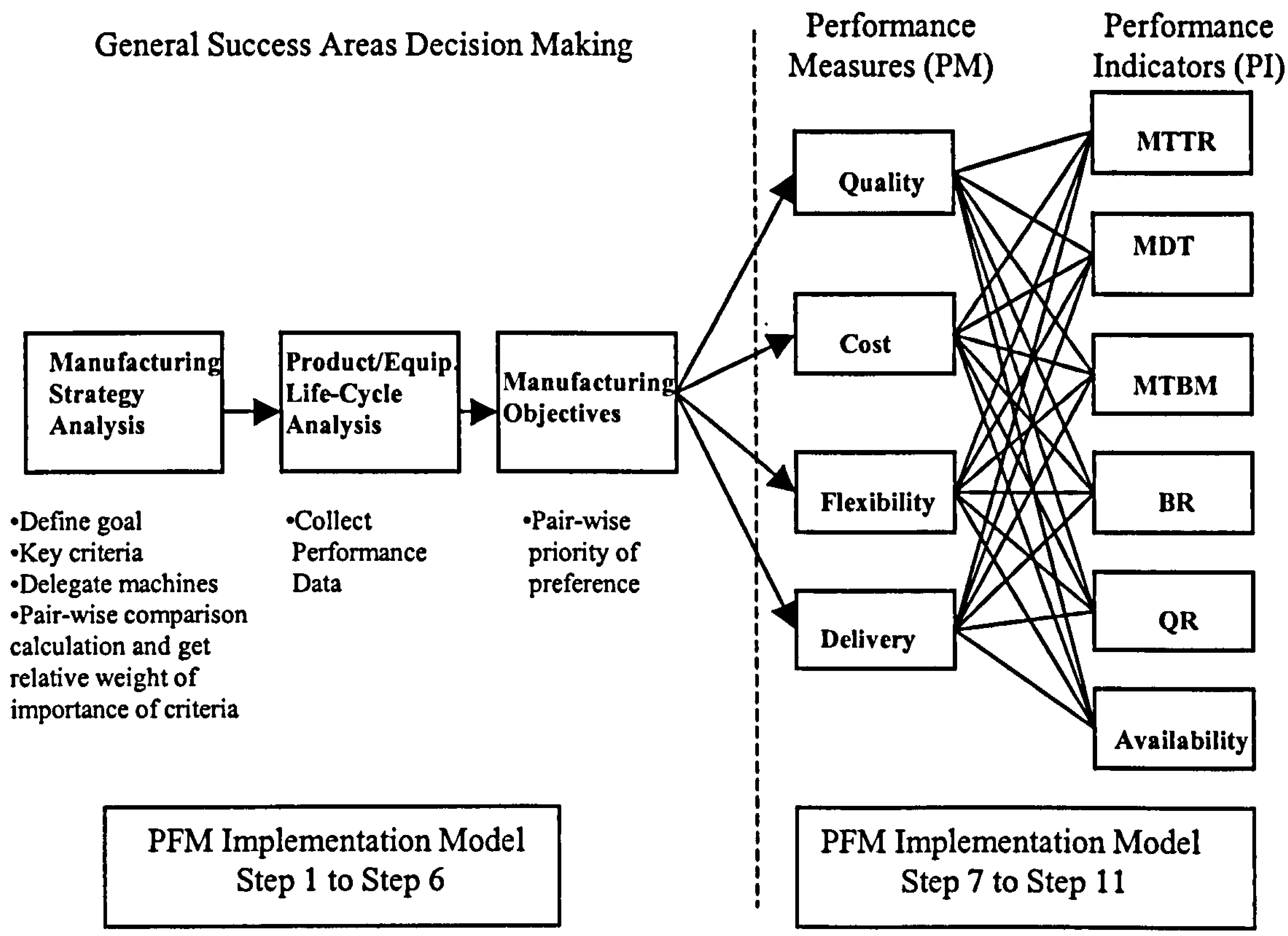


Figure C.1 Example Hierarchical Structure of Performance Measurement System for Decision-Making Assessment of Replacing Existing Facilities

2. ***Step 2: Define the delegate machines involved in decision making assessment.*** The test result is shown in Example 2 of Appendix C.
3. ***Step 3: Derived priorities of each criterion with respect to goal.*** The test result is shown in Example 3 of Appendix C.
4. ***Step 4: Pair-wise comparison of each delegate machine with respect to each criterion*** The test result is shown in Example 4 of Appendix C.
5. ***Step 5: Collecting historic operational data of each machine and pair-wise comparison calculation to get the relative weight of each machine with respect to each criterion (PI).*** The test result is shown in Example 5 and Example 6 of Appendix C.
6. ***Step 6: Total pair-wise comparison of each delegate machine with respect to each criterion*** - The larger the total value means the higher the possibility that the machine will be replaced. The test result is shown in Example 7 of Appendix C.

C.3 Conclusion of the Example Test

This example test brings together the main concepts of the strategically driven PMS developed, the translation of the strategic objectives into the operational requirements, and the application of the MCDM technique (introduced as the AHP process). This test also proves that the conceptual PFM implementation model should have considerable benefits to help the decision-making assessment of the PFM in reality.

Example 1 of Appendix C

Step 1: Define the goal, key criteria (PM/PI) and compare the relative "PREFERENCE" with respect to the Goal.

Goal: Replacing existing facility

Key point - The relative preference of each criterion is decided based on the corporate strategic objective and business focus

replacement policy for existing machines

Node: 0

Compare the relative PREFERENCE with respect to: GOAL

	AV	QR	BR	MTTR	MTBM	MTBR
MDT	(2.0)	(1.5)	2.0	1.0	1.0	1.0
AV		1.4	4.0	2.0	2.0	2.0
QR			3.0	1.5	1.5	1.5
BR				(2.0)	1.0	(2.0)
MTTR					1.0	1.0
MTBM						1.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	replacement policy for existing machines
MDT	Mean Maintenance Downtime
AV	Operational Availability
QR	Quality Rate
BR	Breakdown Frequency
MTTR	Mean Time To Repair
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement

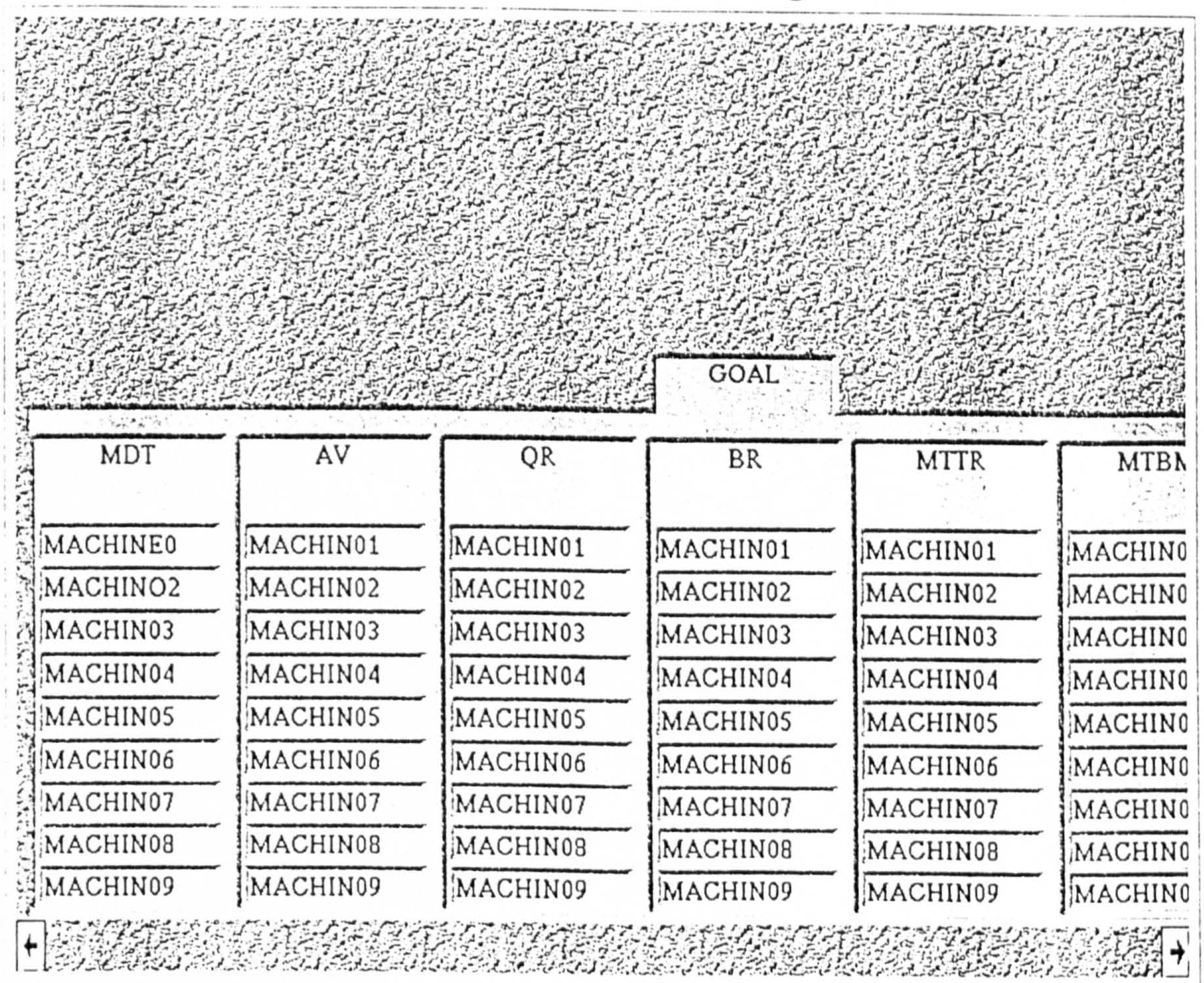
Example 2 of Appendix C

Step 2: Define the delegate machines involved in replacing decision making assessment

Goal: Replacing existing facility

Key point - The delegate machines are those production facilities used to manufacture the products.

replacement policy for existing machines

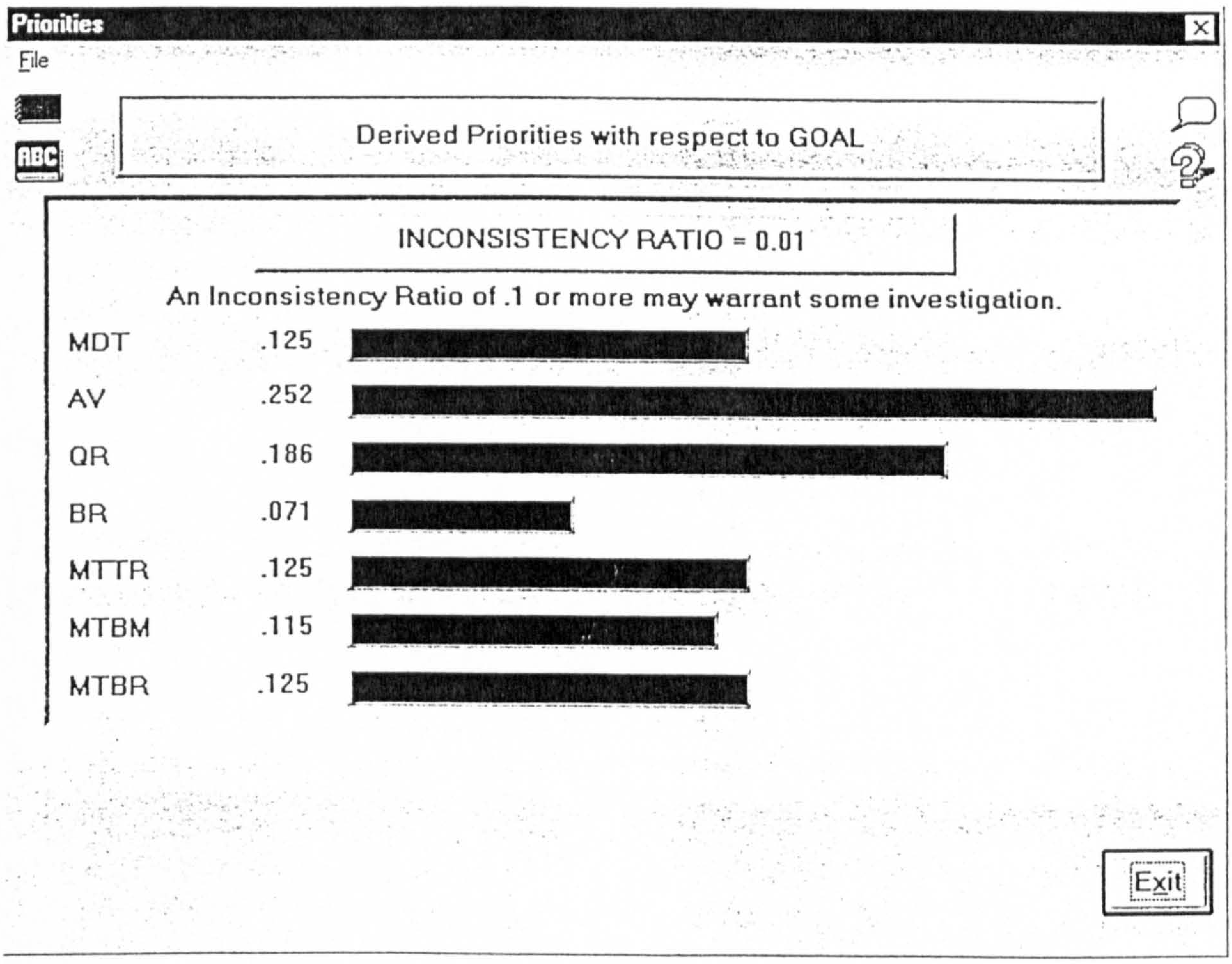


Abbreviation	Definition
AV	Operational Availability
BR	Breakdown Frequency
MACHIN01	Machine01
MACHIN02	Machine02
MACHIN03	Machine03
MACHIN04	Machine04
MACHIN05	Machine05
MACHIN06	Machine06
MACHIN07	Machine07
MACHIN08	Machine08
MACHIN09	Machine09
MACHINE0	Machine01
MACHINO2	Machine02
MDT	Mean Maintenance Downtime
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement
MTTR	Mean Time To Repair
QR	Quality Rate

Example 3 of Appendix C

Step 3: Derived priorities of each criterion (PI) with respect to Goal

Goal: Replacing existing facility



Example 4 of Appendix C

Step 4: Collecting historic performance data of each machine and pair-wise comparison calculation to get the relative weight of each machine with respect to each criterion

Equipment Performance Assessment Table

Competitive criteria	Performance Measure	Unit	Machine01	Machine02	Machine03	Machine04	Machine05	Machine06
Maintainability	Mean Time Between Replacement (MTBR)	hours	500	450	450	500	600	600
	Mean Time Between Maintenance (MTBM)	hours	80	85	90	85	60	70
	Mean Time To Repair (MTTR)	hours	4	4	6	5	5	3
	Mean Maintenance Downtime (MDT)	hours	30	20	20	17	16	12.00
Availability	Operational Availability(Av)	%	72.73	80.95	81.82	83.33	78.95	85.37
Quality	Quality Rate	%	96	99	95	96	94	97
Supportability	Breakdown frequency	No. off order	9	3	16	12	8	4

Example 5 of Appendix C

Step 5: Pair-wise comparison of *each delegate machine with respect to each criterion*

Example 5 shows the relative "PREFERENCE" with respect to goal in the assessment of criterion "MDT".

replacement policy for existing machines

Node: 10000

Compare the relative PREFERENCE with respect to: MDT < GOAL

	MACHINO2	MACHIN03	MACHIN04	MACHIN05	MACHIN06	MACHIN07	MACHIN08	MACHIN09
MACHINE0	1.5	1.5	1.8	1.9	2.5	4.3	5.0	5.0
MACHINO2		1.0	1.2	1.3	1.7	2.9	3.3	3.3
MACHIN03			1.2	1.3	1.7	2.9	3.3	3.3
MACHIN04				1.1	1.4	2.4	2.8	2.8
MACHIN05					1.3	2.3	2.7	2.7
MACHIN06						1.7	2.0	2.0
MACHIN07							1.2	1.2
MACHIN08								1.0

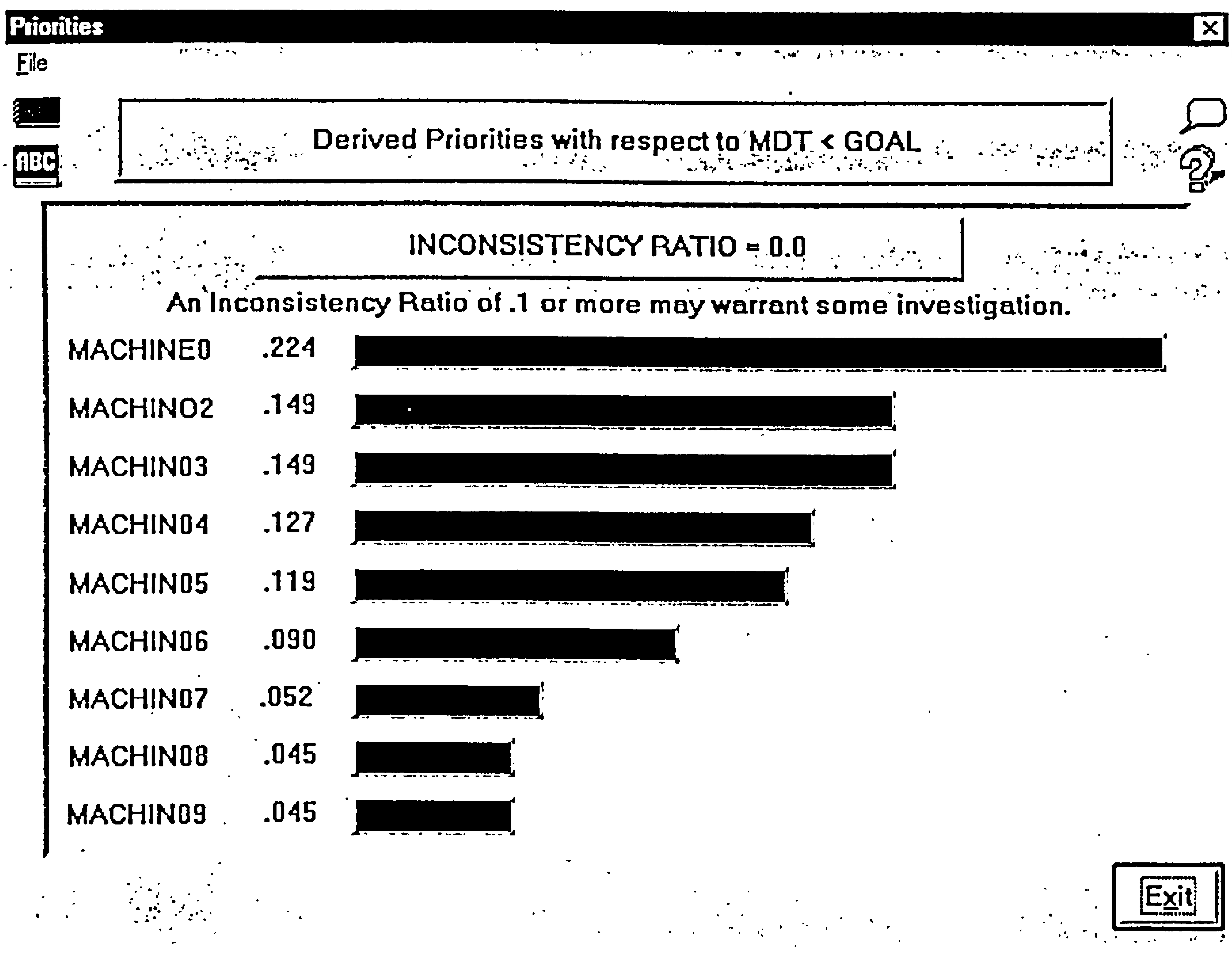
Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	replacement policy for existing machines
MDT	Mean Maintenance Downtime
MACHINE0	Machine01
MACHINO2	Machine02
MACHIN03	Machine03
MACHIN04	Macnine04
MACHIN05	Machine05
MACHIN06	Machine06
MACHIN07	Machine07
MACHIN08	Machine08
MACHIN09	Machine09

Example 6 of Appendix C

Step 5: Pair-wise comparison of each delegate machine with respect to each criterion

Example 6 shows the pair-wise results of the delegate machines with respect to the goal in the assessment of criterion "MDT"

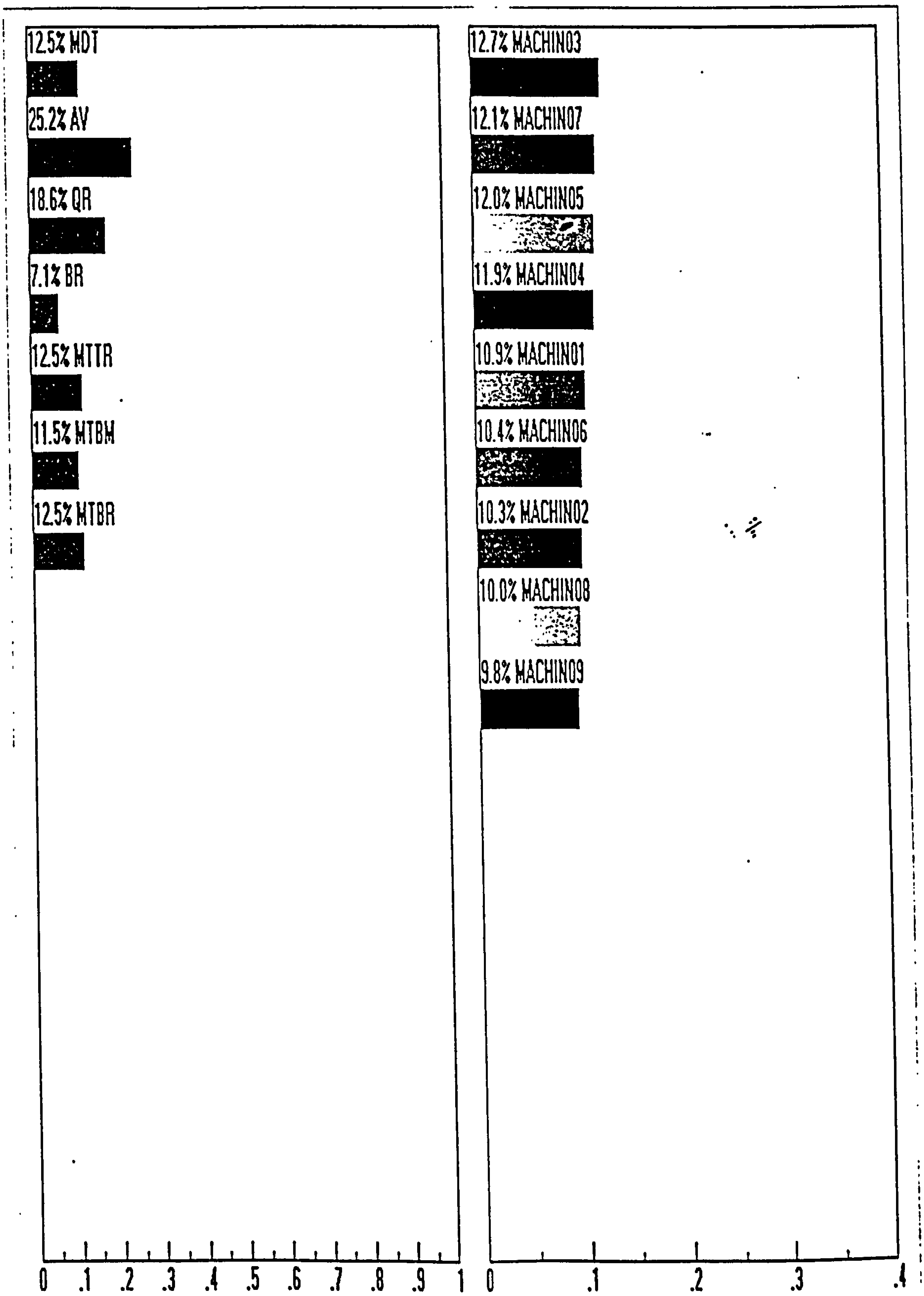


Example 7 of Appendix C

Step 6: Total pair-wise comparison of each delegate machine with respect to each criterion

Key point - The larger the total value means the higher possibility that the machine will be replaced

Dynamic Sensitivity w.r.t. GOAL for nodes below GOAL



Appendix D

Strategically Driven Production Facilities Management (PFM) Implementation Workbook

D.1 The Aim of the Workbook

The aim of this workbook is to provide a generic Production Facilities Management (PFM) framework that is applicable in the manufacturing industry to help a company achieve competitiveness. The outcome will provide an integrated decision-making analysis aid for PFM to assist maintenance, enhancement, or replacement decision-making.

D.2 The Scope of PFM

The PFM concept is based on an integrated system development which is going to link the management of production facilities and equipment to the manufacturing strategic objectives enhanced to provide a step-by-step tool to assist managers in implementing proactive Production Facilities Management (PFM) work.

The implementation process of PFM is gradually translating the ultimate strategic objectives of the corporate level into the manufacturing requirements of the functional level and finally down to the facilities management of the operational level. The process developed in this workbook consists of three main phases, including manufacturing strategy formulation, product/equipment life-cycle assessment and PFM feasibility analysis. Each phase has been further expanded into several working steps. The outcome of each step is an implementation worksheet which functions as a linking table to link the input and output of each step. This well structured implementation process provides a diagnostic assessment procedure to monitor the performance of corporate business competitiveness, and also accomplishes the achievement of Production Facilities Management. The aim of PFM is to support successful business strategy.

D.3 Establishment of a Strategy Review Board

To support the corporate strategic requirements is the ultimate principle of PFM. Strategic concerns are identified and reflected in operational performance in a top-down manner, whereas operational status feedback follows a bottom-up approach to reflect the current performance against the company's strategic goals.

During the implementation process, there are many decisions to be made. A strategy review board should be established. In order to build company-wide consensus, it is recommended that the members of the review board should be composed of the three levels in a company including:

- Corporate level - the executors of the business, such as manufacturing head (V.P., Director, etc.)
- Functional level such as the maintenance manager, engineering, quality, marketing, accounting, human resources, and logistics.
- Operational level - the personnel with the practical operation of the facilities

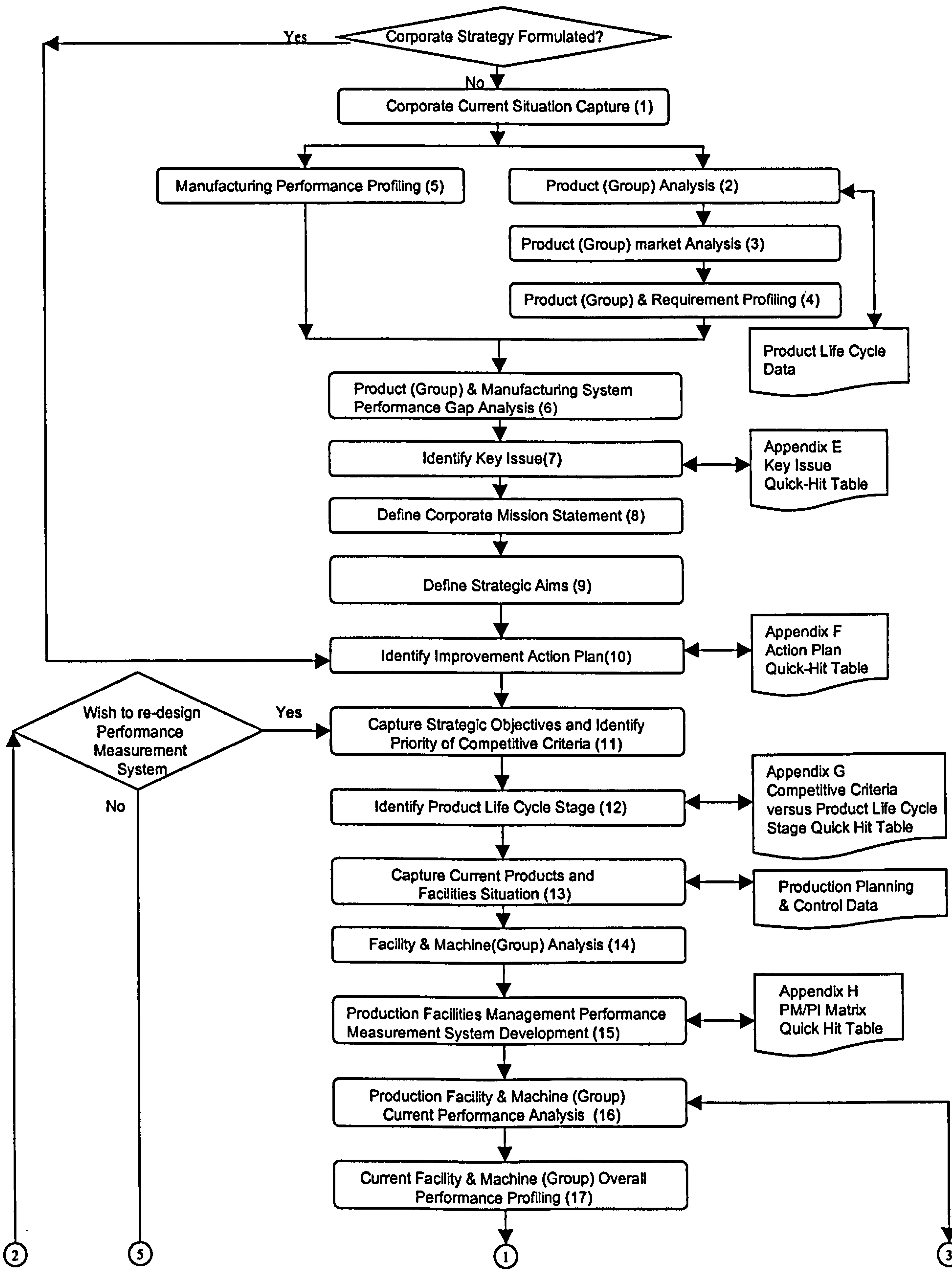
D.4 Contents of the Implementation Workbook

There are two parts of the PFM implementation workbook. Part one is the detailed PFM framework and implementation process and the detailed implementation worksheet for each section of the PFM implementation process. Part two is an example to illustrate the usage of these worksheets for the implementation of PFM framework. The illustrated example is also used as the internal test of the PFM framework.

Part One: PFM Framework and Detailed Implementation Process

Detailed PFM Framework and Implementation Sections

The detailed design of the PFM framework and implementation process and an overview of the PFM process is shown in Figure D.1.


Corporate Strategy Formulated?
Yes
No
Corporate Current Situation Capture (1)
Manufacturing Performance Profiling (5)
Product (Group) Analysis (2)
Product (Group) market Analysis (3)
Product (Group) & Requirement Profiling (4)
Product Life Cycle Data
Product (Group) & Manufacturing System Performance Gap Analysis (6)
Identify Key Issue(7)
Appendix E Key Issue Quick-Hit Table
Define Corporate Mission Statement (8)
Define Strategic Aims (9)
Identify Improvement Action Plan(10)
Appendix F Action Plan Quick-Hit Table
Wish to re-design Performance Measurement System
Yes
No
Capture Strategic Objectives and Identify Priority of Competitive Criteria (11)
Identify Product Life Cycle Stage (12)
Appendix G Competitive Criteria versus Product Life Cycle Stage Quick Hit Table
Capture Current Products and Facilities Situation (13)
Production Planning & Control Data
Facility & Machine(Group) Analysis (14)
Production Facilities Management Performance Measurement System Development (15)
Appendix H PM/PI Matrix Quick Hit Table
Production Facility & Machine (Group) Current Performance Analysis (16)
Current Facility & Machine (Group) Overall Performance Profiling (17)
2
5
1
3

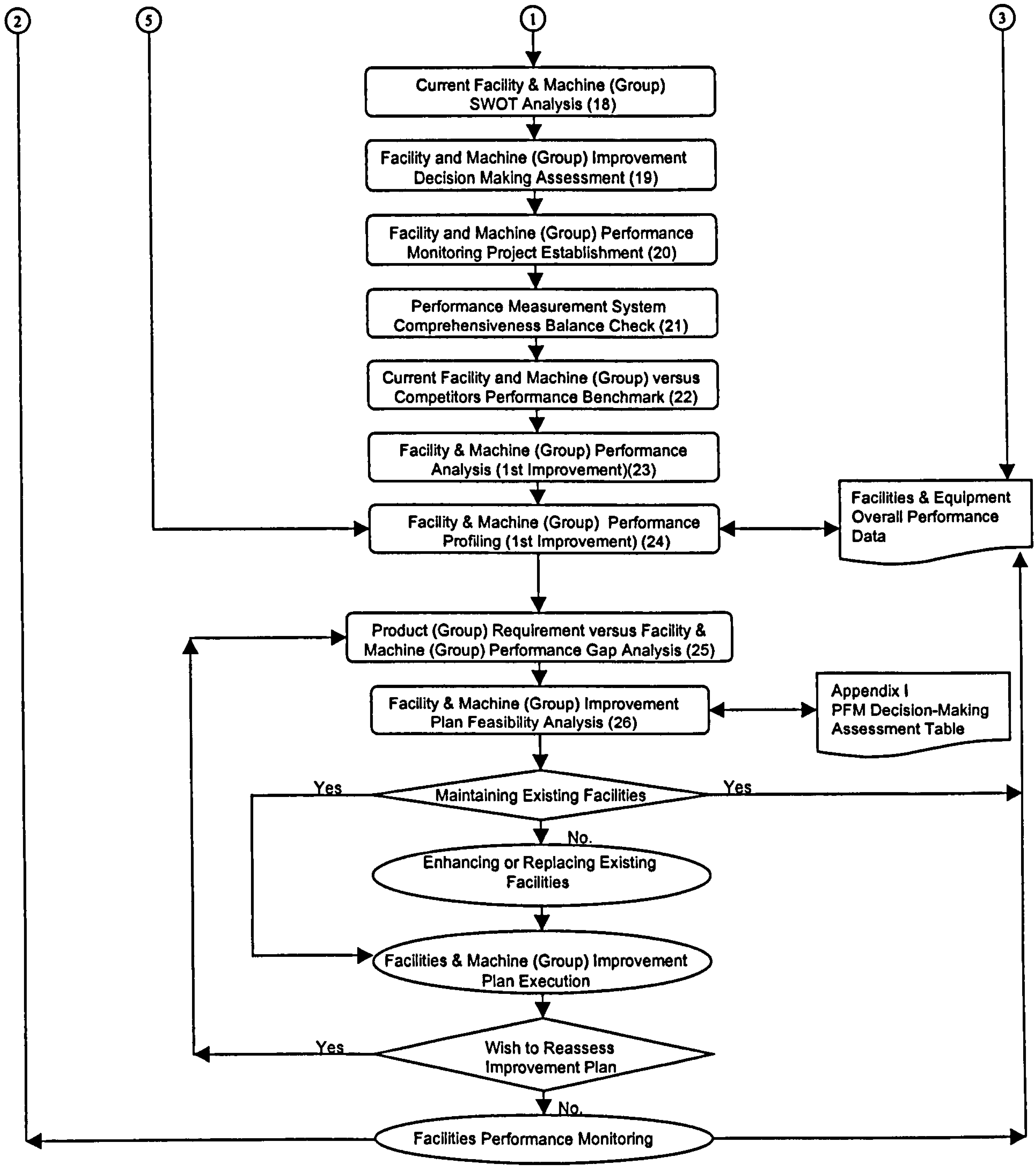


Figure D.1 Detailed PFM Framework Implementation Process

Detailed Description of Each Section and Worksheet of the Implementation Process

Each section of the implementation process is associated with a linking table which provides the linkage between the sections. Following the workbook will illustrate each worksheet with the aim, description of the implementation procedure and an example case for the fulfilment after each worksheet.

Section 1: Corporate Current Situation Capture

Aim: Establishment of the background data of the state of the corporation.

Description: The worksheet can be composed of a set of questions. The questions contained in this section provide the background data that are required by the strategy review board to assess the capability of the business, its organisation and its manufacturing system. The output of the section also helps the members of the review board to increase their understanding of the relationship between business and manufacturing so as to contribute the strategic concerns. The business can be classified with respect to the business structure, business culture organisation behaviour and operating environment. The manufacturing system can be classified with respect to product-process matrix. The typical factors used for classification include the types of manufacturing process such as the project type, jobbing type, batch type and mass production type; the volume and variety of the products, process flexibility and the total cost.

The definition of the role of manufacturing function is the final step in this section. It requires the review board synthesising the corporate situation and concluding the structure of the manufacturing system with respect to the process/product matrix. Different classification of the manufacturing system will influence the decision making of PFM.

Worksheet 1:

Business/organisation classification	
A. Business Definition	
1. What is the business?	
2. Who are the customers?	
3. Who are the competitors?	
B. Business structure	
1. Type of centralisation (centralised or decentralised)	
2. Size of the company	
3. Hierarchical structure of the organisation (structural tree of the departments)	
C. Business Culture	
Ownership	
D. Organisational behaviour	
1. Organisational process (job, project, batch, line or continuous)	
2. Market position (growth, maturity, new products or decline)	
E. Operating environment	
1. Business purpose	
2. Technology	

Section 2: Product (Group) Analysis

Aim: Identify the key product (group)

Description: The Production Facilities Management deals with the product requirements and facilities requirements in operation throughout the life cycle of each product (group). The aim of product (group) analysis is analysing the relative weight of importance of each product (group) by some agreed monitoring parameters. Typical but not exhaustive measures utilised for this analysis are recommended in the following table. The result is to allocate the relative weight of importance of each product (group). The relative weight of importance of each product (group) will sequentially decide the weight of importance of each machine (group) used to produce it. The products that have a higher weight of importance are the key products to be monitored and all of the facilities to produce them are the key machines (groups) to be supported. The accumulation of the historic market and production data of each product (group) will reflect the distribution of the life cycle of each product. The measures used in this analysis should be periodically reviewed by the review board, so as to plan and control the deviation of the manufacturing environment.

Worksheet 2

Measures of the Product (Group) Analysis	Products (Groups)				
	Product 1	Product2	Product3	Product4	Product ...
Variants					
Volume					
Sales					
% of Total Sales					
% Contribution					
Market Share					
Growth Opportunities					
Degree of Innovation					
Principle Processes					
Materials					
Approximate Profit/ Cost/Sales					
Typical Order Size					
Market Focus					
Relative Importance of Products (Groups)					

Section 3: Product (Group) Market Analysis

Aim: Draw the strategic requirements profiling of the key products (groups)

Description: The purpose of product (group) market analysis is to help the company to obtain a detailed understanding of what the requirement of each product (group) is by the customers in a chosen market segment. Different competitive factors required by customers imply different performance objectives.

A number of parameters have been suggested for the assessment of the market requirement of each product (group). The typical parameters are:

- *Product features*: Adding capability to the product, or choice for the customer
- *Quality:* Conformance to specification, reliability in use
- *Delivery lead time*: Delivering the product within the lead time required by the customer
- *Delivery reliability*: Always delivering to schedule
- *Design flexibility* Having the ability to produce products to a customer specification (customisation)
- *Volume flexibility*: Having the ability to supply fluctuating volumes without compromising lead time
- *Price*: Selling at the lowest price

The above parameters are typical but not exhaustive measures and can be supplemented and customised to meet the specific requirements of the business. The following table illustrates typical relationships between these customers requirements and the performance objectives.

Competitive Factors (If the customers value these...)	Performance Objectives (Then, the operation will need to excel at these...)
Low price	Cost
High quality	Quality
Fast delivery	Speed
Reliable delivery	Dependability
Innovative products and services	Flexibility (product and service)
Wide range of products and services	Flexibility (products and services)
The ability to change the timing or quantity of products and services	Flexibility (volume and/or delivery)

These market requirements will initiate the implementation of all development and investment required in the process, technology and infrastructure of the firm.

Worksheet 3

Performance Requirements	Product1	Product2	Product3	Product4	Product...	Overall Requirement
Quality						
Delivery Lead Time						
Delivery Reliability						
Design Flexibility						
Volume Flexibility						
Cost						
Relative Weight of Importance of Each Product (Group)						

Section 4:Product (Group) and Requirement Profiling

Aim: Draw the strategic requirements profiling of the key product (group)

Description: The aim of product requirement analysis is to assess the performance of each product (group) from the external customer's perspective. This analysis uses the matrix of product (group) with respect to the customers requirements which are shown in six competitive criteria: quality, delivery lead time, delivery reliability, design flexibility, volume flexibility and cost. The overall customer requirement shows the performance of the company which is obtained by calculating the average Utility Value (UV) of each product (group) with respect to each customer requirement. The maximum customer requirement is derived from the maximum value of the customer requirement with respect to each competitive criterion in each product (group). The maximum customer requirement in each competitive criterion is the target value for the whole manufacturing system to approach.

The following table illustrates the method used to implement the overall Utility Value (UV) calculation.

Customers Requirements (Competitive Criteria)	Product 1	Product 2	Product 3	Product (n)	Overall Customers Requirements on Each Criterion
Q	A1	A2	A3	An	OP (Q)
DLT	B1	B2	B3	Bn	OP (DLT)
DR	C1	C2	C3	Cn	OP (DR)
DF	D1	D2	D3	Dn	OP (DF)
VF	E1	E2	E3	En	OP (VF)
C	F1	F2	F3	Fn	OP (C/P)
Weight of Importance of Each Product (Group)	P1	P2	P3	Pn	

The Overall Customers Requirements for each criterion is calculated as follows:

1. OP (Q) = A1*P1 + A2*P2 + A3*P3 +.....+ An*Pn
2. OP (DLT) = B1*P1 + B2*P2 + B3*P3 +.....+ Bn*Pn
3. OP (DR) = C1*P1 + C2*P2 +C3*P3 +.....+ CN*Pn
4. OP (DF) = D1*P1 + D2*P2 + D3*P3 +.....+ Dn*Pn
5. OP (VF) = E1*P1 + E2*P2 + E3*P3 + ...+ En*Pn
6. OP (C/P) = F1*P1 + F2*P2 + F3*P3 +.....+Fn*Pn

In order to assist the visual presentation of the result, the Polar diagram is also used in this section. The deviation between the maximum customers requirements and the overall customers requirements also decides the priority of improvement on each competitive criterion from the customer's perspective.

Worksheet 4

Customer Requirements	Product1	Product2	Product3	Product ...	Overall Customer Requirement	Maximum Customer Requirement	Deviation	Improvement Priority
Quality								
Delivery Lead Time								
Delivery Reliability								
Design Flexibility								
Volume Flexibility								
Cost/Price								
Relative Importance								

Section 5: Manufacturing Performance Profiling

Aim: Establishment of the manufacturing performance profiling.

Description: The method is to assess the performance of each product (group) from an internal manufacturing perspective. This self-assessment will help in understanding the company's performance in supplying the products to satisfy customer requirements. This analysis uses the same matrix table of product (group) analysis with respect to the six typical competitive criteria (quality, delivery lead-time, delivery reliability, design flexibility, volume flexibility and cost) so as to keep consistency with the product (group) profiling. The difference between section four and section five is the respondents of the investigation, the former are customers and the latter are internal operators. There are three kinds of information to be obtained in the profile.

1. ***Overall performance data*** – This will provide an averaged performance of the whole manufacturing system with respect to each competitive criterion from a manufacturing system viewpoint. The performance of the manufacturing system is also assessed with respect to each product (group).
2. ***Maximum performance data*** - This data is derived from the maximum value of the manufacturing system requirements with respect to each competitive criterion in each product (group). The maximum performance requirements provides the integrated target value in each competitive criterion for the manufacturing system to approach.
3. ***Deviation of maximum manufacturing system requirement and overall manufacturing system requirement with respect to each competitive criterion*** – The deviation between the maximum manufacturing system requirements and the overall manufacturing system requirements also decides the priority of improvement on each competitive criterion from the internal manufacturing system perspective.

The UV calculation and Polar diagram can also be applied in this section so as to assist the analysis. The following table illustrates the method used to implement the overall Utility Value (UV) calculation.

Manufacturing System Requirements (Competitive Criteria)	Product 1	Product 2	Product 3	Product (n)	Overall Manufacturing System Requirements on Each Criterion
Q	A1	A2	A3	An	OP (Q)
DLT	B1	B2	B3	Bn	OP (DLT)
DR	C1	C2	C3	Cn	OP (DR)
DF	D1	D2	D3	Dn	OP (DF)
VF	E1	E2	E3	En	OP (VF)
C	F1	F2	F3	Fn	OP (C/P)
Weight of Importance of Each Product (Group)	P1	P2	P3	Pn	

The overall manufacturing system requirements for each criterion is calculated as follows:

1. OP (Q) = A1*P1 + A2*P2 + A3*P3 +.....+ An*Pn
2. OP (DLT) = B1*P1 + B2*P2 + B3*P3 +.....+ Bn*Pn
3. OP (DR) = C1*P1 + C2*P2 +C3*P3 +.....+ CN*Pn
4. OP (DF) = D1*P1 + D2*P2 + D3*P3 +.....+ Dn*Pn
5. OP (VF) = E1*P1 + E2*P2 + E3*P3 + ...+ En*Pn
6. OP (C/P) = F1*P1 + F2*P2 + F3*P3 +.....+Fn*Pn

Worksheet 5

Manufacturing System Requirements	Product1	Product2	Product3	Product ...	Overall Manufacturing System Requirement	Maximum Manufacturing System Requirement	Deviation	Improvement Priority
Quality								
Delivery Lead Time								
Delivery Reliability								
Design Flexibility								
Volume Flexibility								
Cost/Price								
Relative Importance								

Section 6: Product (Group) and Manufacturing System Performance Gap Analysis

Aim: The aim of product (group) and manufacturing system performance gap analysis is to analyse the deviation between the customer requirement and the performance of the current manufacturing system.

Description: The method is to compare the maximum UV value from the manufacturing performance profiling (section five) and the maximum UV value from the product (group) requirement profiling (section four) with respect to each competitive criterion. The goal is to identify the deviation between the requirements of external customers and the actual performance of internal assessment with respect to each competitive criterion. The deviation will provide the priority of improvement in each competitive criterion. The larger the gap in a specified competitive criterion means that there are more improvement actions required to improve its performance. The Polar diagram can be used to assist the visual presentation.

Worksheet 6

Competitive Criteria	Manufacturing System Performance (Maximum manufacturing system performance derived from Section 5)	Key Product (Group) Requirement (Maximum product requirements derived from Section 4)	Deviation	Improvement Priority
Quality				
Delivery Lead Time				
Delivery Reliability				
Design Flexibility				
Volume Flexibility				
Cost				

Section 7: Identify Key Issues

Aim: Identify the key issue of the performance gap between product requirements and manufacturing system

Description: Key issues are events, trends, facts or realities which may have a significant impact on the organisation in general or manufacturing in particular. Many issues only rise to the surface after thorough analysis, in particular an analysis that is inter-disciplinary and multiple-dimensional in nature. The aim of this step is to analyse the reason why there is a gap between the product (customer) requirements and the overall performance of the manufacturing system (production facilities and equipment). The key requirement in implementation is to induct these key issues with respect to the competitive criteria. Typical but not exhaustive issues which cause the gap are listed in Appendix E. After synthesising the user's experience and refering to this provided reference table, the key issues can be identified and the strategic improvement objectives can be obtained sequentially.

Worksheet 7

Issues	Strategic Improvement Objectives	Priority to be improved	Relations to the Competitive Criteria					
			Q	DLT	DR	DF	VF	C/P

Section 8: Define Corporate Mission Statement

Aim: Define corporate mission statement

Description: With the background, the manufacturing strategy is formulated by developing a mission statement for the manufacturing unit. The strategy addresses the key competitive issues identified in the corporate mission statement. The mission statement is normally described in terms of the aforementioned competitive criteria such as quality, delivery, flexibility, cost and combination of the minds of the top management. The key point is that the priority of these criteria should be identified on the basis of the corporate background so as to generate the priority of the decisions to be made. The mission statement formulates the strategic objective manufacturing to approach.

Worksheet 8

Corporate Mission Statement:

Section 9: Define Strategic Aims

Aim: Define the strategic aims

Description: A strategic aim is a broad, usually qualitative but result-oriented statement of what must be achieved within the time horizon of the strategy. It provides direction and is a fundamental change in the way we carry out business/manufacturing related activity. In total, strategic aims are the direct responses to the key issues and therefore should be consistent with the functional definition of the organisation and are the basis for the company to gain competitive advantages.

Although the strategic aims are direct responses to the key issues, the responses do not have to be on a one for one basis. One particular strategic aim may cover more than one issue. Formulation of the strategic aims is achieved by analysing the current manufacturing policy of the firm and by planning future policy. The manufacturing policy is shown with respect to some decision-making areas. Typical decision-making areas are: capacity, facilities, process and technology, vertical integration, supplier development, human resources, quality systems, planning and control, product scope and new products, performance measures, and organisation.

Worksheet 9

Corporate Competitive Criteria	*Key Issues*	*Manufacturing Aims*
Quality		
Delivery lead time		
Delivery reliability		
Design Flexibility		
Volume flexibility		
Cost		

Section 10: Identify Improvement Action Plan

Aim: Identify improvement action plan

Description: The improvement action plan is a set of improvement suggestions based on strategic aims and key issue identification. The generating process of this plan is to define the required action with respect to each manufacturing policy decision-making area. With respect to the decision-making areas, a number of action plans can be developed. An action plan quick hit table is developed in this research which is shown in Appendix F. The items developed in Appendix F are typical but not exhaustive ones. The company should develop the proper one to fit its own situation.

Worksheet 10

Policy Area	*Improvement Action Items*
Capacity	
Facilities	
Process and Technology	
Vertical Integration	
Supplier Relations	
Human Resources	
Quality System	
Production Planning and Control	
New Product Introduction and Scope	
Performance Measurement	
Organisation	

Section 11: Capture Strategic Requirements and Identify Priority of Competitive Criteria

Aim: Capture the strategic objectives and identify the priority of the competitive criteria of the business.

Description: The implementation of the corporate strategy is composed of many trade-offs in different policy decision-making areas. The activities that are implemented in Production Facilities Management (PFM) are more focused on assuring these strategic requirements can be supported and accomplished as a whole. The step of capturing the manufacturing strategic requirements from the manufacturing strategy formulation phase is the first step to link the manufacturing strategy with the following PFM implementation sections. The total performance of the existing manufacturing system can be broken down into the performance of individual facility and machine (group). The performance of each facility and each machine (group) will influence the competitiveness of the corporation in the end. The key point of this section is to capture the strategic requirements especially those related to the operation of the current facilities. These strategic requirements are derived from the strategic aims with respect to each policy decision-making area.

The typical policy areas and content of the manufacturing strategy have been discussed by several researchers. Typical ones are capacity, facilities, process and technology, vertical integration, supplier relations, quality systems, production planning and control, new product introduction and scope, performance measurement, and organisation.

The purpose of this section is to capture all of the manufacturing strategic requirements which are derived from strategic aims and improvement action plans in these typical policy decision-making areas so as to establish a company-wide consensus in achieving PFM work. The implementation of each objective in each policy decision-making area will sequentially influence the competitiveness of the company which is turned up in six forms: Quality (Q), Delivery Lead Time (DLT), Delivery Reliability (DR), Design Flexibility (DF), Volume Flexibility (VF) and Cost/Price (C/P). A linking table for the description of the intermix relationship between each policy area and competitive criteria is shown in the following table.

Worksheet 11

Policy Decision-Making Area	Policy (Strategic Requirements)	Competitive Criteria					
		Q	DLT	DR	DF	VF	C/P
Capacity							
Facilities							
Process and Technology							
Vertical Integration							
Supplier Relations							
Human Resources							
Quality System							
Production Planning and Control							
New Product Introduction and Scope							
Performance Measurement							
Organisation							
Analysis subtotal							
Priority of the competitive criteria							

Note:

1. Q = Quality
2. DLT = Delivery Lead Time
3. DR = Delivery Reliability
4. DF = Design Flexibility
5. VF = Volume Flexibility
6. C/P = Cost / Price
7. The strategic objectives are generated through the discussion of an organised team. The team members should include the management level, functional level and operational level.
8. Tick "x" in the column of each competitive criterion. If each "x" is equal to a score of "20", the subtotal score for each criterion can be added together as a subtotal score under each criterion.
9. The subtotal score of each criterion also decides the priority of the competitive criteria.

Section 12: Identify Product Life Cycle Stage

Aim: Identify product life cycle stage

Description: The function of a production facility is to transfer raw materials into profitable products. Every product has its own product life cycle stage. The demand of the customer (market) will decide the life cycle stage of the product and sequentially influence the management of the production facility or machine (group). A typical life cycle of a product (group) is divided into five stages: concept, design and development, production, decline, and rapid decline. Different stages of a product's life cycle decide the different weight of importance of the product (group). The identification of the product's life cycle stage is based on the data analysis from the product (group) analysis in section two.

The identification of the product's life cycle stage will sequentially influence the weight of importance of each competitive criterion. To find a balance amongst these criteria by sequentially deciding the priority of them is a critical step in PFM. Each company should make its own choice of their priorities so as to match the corporate background. An example quick hit table to illustrate the relationship between the weight of importance of the competitive criteria with respect to the life stage of a product (group) is developed in the research and is shown in Appendix G. The matrix table of the weight of importance of the competitive criterion with respect to the life cycle stages should be determined and assessed periodically by the review board.

Worksheet 12

Product (Group)		Product (Group) Life Cycle Stage					
Item	Product (Group)	Concept	Design and Development	Production	Decline	Rapid Decline	Relative Importance
1	Product 1						
2	Product 2						
3	Product 3						
4	Product 4						
5	Product 5						
6	Product...						

Section 13: Capture Current Products and Facilities Situation

Aim: Analysing the status of production and utilisation of the machine (group) to produce these products.

Description: The data to be analysed are derived from production planning and control databank. The goal is to identify the key product (group) and key machine (group) so as to predict the working load of each machine with respect to each product in the future. Each machine (group) to produce the key products is the key machine (group) to be monitored and supported. A number of parameters can be used to analyse the relationship between the current product and facilities situation. Typical parameters are: production years at present, expected production years, total number of products required, unit working hours on each machine (group), and total working hours required on each machine (group). However, every company should define its own parameters for the production status and the future requirement analysis.

Worksheet 13

Item	Indicators	Existing Products		New Products		Sub Total
		Product1	Product2	Product3	Product...	
1	Production year (present)					
2	Production year (expected)					
3	Product life (present/expected) * %					
4	Number of products required (pieces)					
5	Number of products produced (pieces)					
6	Required working hour per unit					
7	Total used working hours					
8	Unit working hour on machine 1					
9	Unit working hours on machine *					
10	Total required working hours on machine1					
11	Total required working hours on machine *					
12	Total used working hours on machine 1					
13	Total used working hours on machine *					
14	Total products produced on machine 1					
15	Total products produced on machine *					

Section14: Facilities and Machine (Group) Analysis

Aim: This section aims to group the key facility and machine (group) and decide the relative importance of them.

Description: The facilities and machine (group) analysis provides a tool to aid the grouping of existing facilities and machines (group). Typical but not exhaustive parameters in the application are listed in the following worksheet. By the application of Utility Value (UV) calculation, the relative importance of each machine (group) can be decided. The relative importance of each machine (group) will sequentially influence the decision to make in maintaining, enhancing or replacing them in the end.

Worksheet 14

Facilities specification items	Relative importance of each specification item (Shown in %)	Degree of each item (shown in High, Medium, and Low)	Weight of Degree of each Item (Shown in score)	Mach1	Mach2	Mach3	Mach.x
Original Purchasing Price	a %			A1	A2	A3	Ax
Process Type	b %			B1	B2	B3	Bx
Precision Specification	C %			C1	C2	C3	Cx
Throughput Time	d %			D1	D2	D3	Dx
Productivity	e %			E1	E2	E3	Ex
Space Utilisation	f %			F1	F2	F3	Fx
Calibration Requirement	g %			G1	G2	G3	Gx
Expected Service Period	h %			H1	H2	H3	Hx
Maintainability	i %			I1	I2	I3	Ix
Operational Capacity	j %			J1	J2	J3	Jx
Utility Consumption	k %			K1	K2	K3	Kx
Breakdown Frequency	l %			L1	L2	L3	Lx
Quality Rate	m %			M1	M2	M3	Mx
Availability	n %			N1	N2	N3	Nx
Annual Maintenance Cost	o %			O1	O2	O3	Ox
Total Maintenance Cost	p %			P1	P2	P3	Px
Functional Replacement Ability	q %			Q1	Q2	Q3	Qx
Others							
Weight of each machine				W1	W2	W3	Wx
Relative Importance to each other				R1	R2	R3	Rx

Note:

1. The weight of each machine is calculated by the application of Utility Value methodology.
2. The Utility Value of the weight of each machine (Wx) is calculated by
   Wx=(Ax*a)+Bx*b)+(Cx*c)+(Dx*d)+(Ex*e)+(FX*f)+(Gx*g)+(Hx*h)+(Ix*I)+(Jx*j)+(Kx*k)+(Lx*l)+(Mx*m)+(Nx*n)+(Ox*o)+(Px*p)+(Qx*q)
3. The relative importance of the machine with respect to the others (Rx) is calculated by
   Rx =Wx / (W1+W2+W3+...+Wx)

Section 15: Production Facilities Management Performance Measurement System (PFMPMS) Development

Aim: This section aims to develop a performance measurement system for the identification of the hierarchy of the competitive criteria, Performance Measures (PM) and Performance Indicators (PI).

Description: Each company can make its own choice of these competitive criteria, PM and PI with respect to the type of industry, production methods, manufacturing process, and technology. A hierarchical structure of the PFM PMS is formulated as shown in the following Figure.

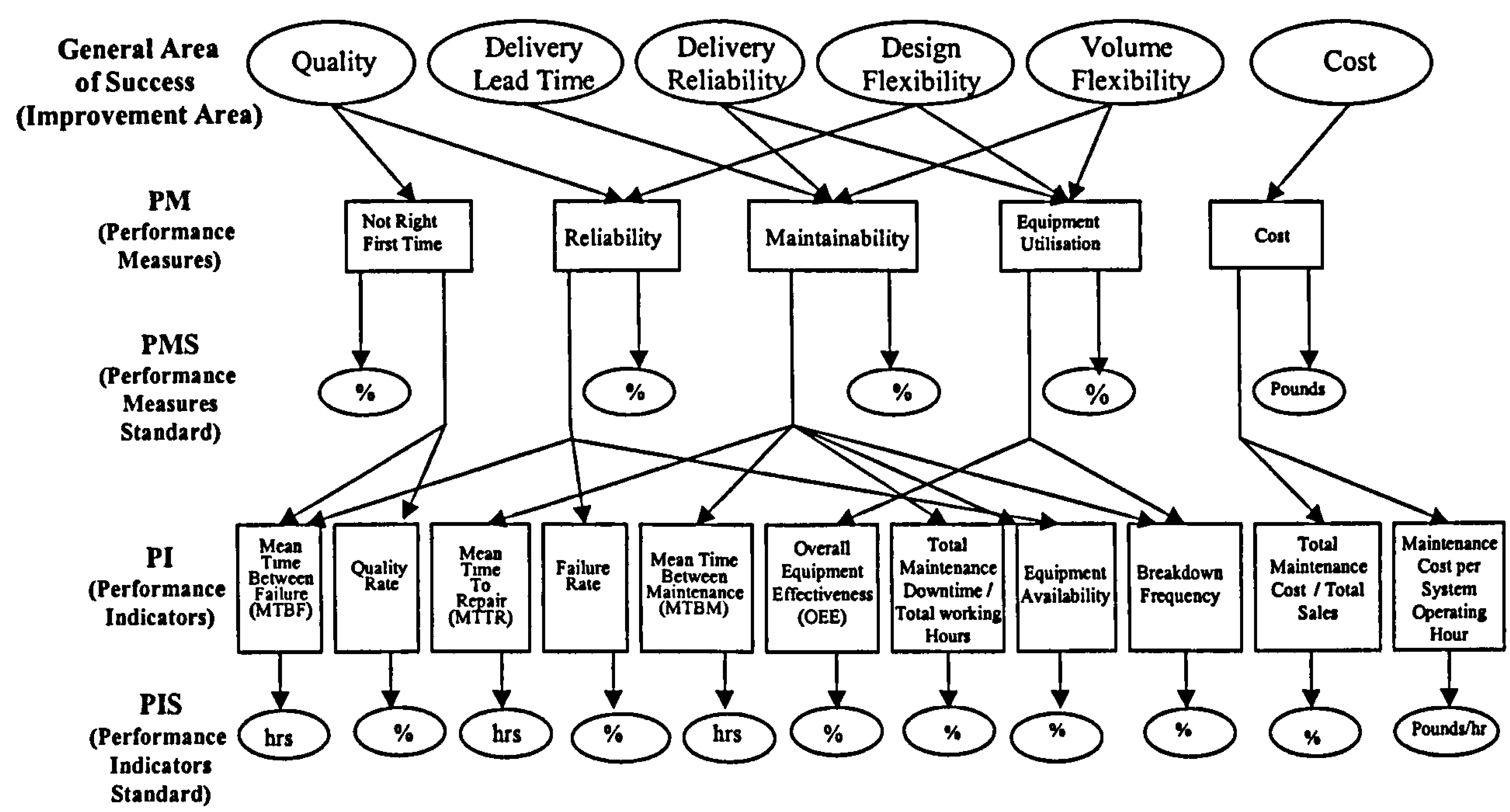


Figure D.2 Performance Measurement System Tree In PFM

This diagram shows the hierarchy of the different activities within the organisation and supports the notion that these activities should be measured, controlled, and improved in order to achieve the stated strategic objectives (e.g. reliable delivery). The performance measurement system tree in PFM consists of the performance measurement requirements in three levels of the organisation, these being the corporate level, functional level and operational level. Figure D.2 also shows how the performance measures and the performance indicators for different areas of success are related. Identifying the interactions between the different performance measures and performance indicators helps the company determine how to improve the performance of several areas of success by focusing on one performance indicator. The hierarchy of the system also specify the methodology to translate the strategic objectives (general area of success) into the requirements of implementation in the operational level (performance measures and performance indicators).

A typical matrix table also used to illustrate the relationship between these competitive criteria, PM and PI is shown in Table 5.4.

Worksheet 15

Competitive Criteria, Performance Measures and Performance Indicators Matrix Table

Competitive Criteria						Performance Measures	Performance Indicators					
Q	DLT	DR	DF	VF	C/P		Mean Corrective Time	Breakdown Frequency	Set-up Times	MTBM	MTBR	Others
						Maintainability						
						Reliability						
						Availability						
						Labour						
						Supportability						
						Skill						
						Tooling						
						Calibration						
						Capacity						
						Construction						
						Documentation						
						Dimension						
						Space Utilisation						
						Productivity						
						Lay-out						
						Location						
						Cost Factors						
						Safety						
						Quality Factors						
						Delivery Schedule Achievement						
						Others						

In this research, a recommended PM/PI convertible matrix is developed in the PFM implementation workbook which is shown in Appendix H. The structure of the PFM PMS should be periodically reviewed by the strategy review board so as to keep up with the changing environment.

Worksheet 15

Competitive Criteria, Performance Measures and Performance Indicators Matrix Table

Competitive Criteria						Performance Measures	Performance Indicators					
Q	DLT	DR	DF	VF	C/P		Mean Corrective Time	Breakdown Frequency	Set-up Times	MTBM	MTBR	Others
						Maintainability						
						Reliability						
						Availability						
						Labour						
						Supportability						
						Skill						
						Tooling						
						Calibration						
						Capacity						
						Construction						
						Documentation						
						Dimension						
						Space Utilisation						
						Productivity						
						Lay-out						
						Location						
						Cost Factors						
						Safety						
						Quality Factors						
						Delivery Schedule Achievement						
						Others						

In this research, a recommended PM/PI convertible matrix is developed in the PFM implementation workbook which is shown in Appendix H. The structure of the PFM PMS should be periodically reviewed by the strategy review board so as to keep up with the changing environment.

Section 16: Facilities and Machine (Group) Current Performance Analysis

Aim: This section aims to record the operational data of each machine (group).

Description: The key point of the implementation is to determine the appropriate parameters to monitor the performance of facilities and machines (group). A number of parameters are recommended for operational data collection and analysis. Even though it is recommended to be as comprehensive as possible, it is not necessary to use all of them in decision-making of maintaining, enhancing or replacing these machines. These data also provide the background data for the performance gap analysis. The data to be recorded should be chosen through the commitment of management, functional and operational levels within the company.

Worksheet 16

Performance Measures (PM)	Performance Indicators (PI)	Unit	Mach1	Mach2	Mach3	Mach ...
Maintainability	Mean Time To Repair (MTTR)					
	Mean Corrective Time					
	Mean Preventative Maintenance Time					
	Mean Active Maintenance Time					
	Mean Time Between Replacement (MTBR)					
	Mean Time Between Maintenance (MTBM)					
	Mean Logistics Delay Time (MLDT)					
	Mean Administrative Delay Time (MADT)					
	Mean Maintenance Down Time (MDT)					
	Replacement Frequency (RF)					
Reliability	Breakdown Frequency (BR)					
	Failure Rate (FR)					
	Total Operating Hours					
	Mean Time Between Failure (MTBF)					
Labour	Maintenance Man Hours per System Operating Hour (MMH/OH)					
	Maintenance Man Hours per Month (MMH/M)					
	Maintenance Man Hours per Maintenance Action (MMH/MA)					
	Total Products Produced					
Cost Factors	Maintenance Cost per System Operating Hour					
	Cost per Maintenance Action					
	Total Maintenance Cost					
	Total Maintenance Cost / Total Life Cycle Cost					
	Total Maintenance Man Hours					
Quality Factors	Quality Rate (QR)					
	Quality Product Numbers					
	Total Products Produced					
Flexibility Factors	Availability (Schedule Time – All Unplanned Time) / Schedule Time					
	Process Rate (Ideal Cycle Time / Actual Cycle Time) = Efficiency Ratio					
	Actual cycle Time = Total Working Hours + Total Maintenance Man Hours (Includes LDT and ADT)					
	Overall Equipment Effectiveness					

Section 17: Current Facilities and Machine (Group) Overall Performance Profiling

Aim: Establishment of the overall performance profiling of the key machine (group)

Description: The aim of this profiling is to get the overall performance of each existing machine (group) with respect to each competitive criterion. The overall performance of each machine (group) can be determined by six competitive criteria such as quality, delivery reliability, delivery lead time, design flexibility, volume flexibility, and cost. The performance of each criterion can be divided into subordinate performance measures and indicators. The choice of the performance measures and indicators is decided by the organised PFM team. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirement. This result also provides an assessment for the second stage of the improvement plan.

Worksheet 17

One of the overall performance analysis techniques is the Utility Value (UV) calculation theory. The application of this calculation is divided into two kinds of situation: single indicator for each criterion and multiple indicators for each criterion. They are described in the following cases:

Case one: For single indicator for each criterion

Competitive Criterion	Weight of Importance of each Criterion	P. M.	P. I.	Unit	Mach1	Mach2	Mach3	Mach(n)	Overall Performance
Weight of Importance of machine					M1	M2	M3	Mn	
Q	X1				A1	A2	A3	An	OP (Q)
DLT	X2				B1	B2	B3	Bn	OP (DLT)
DR	X3				C1	C2	C3	Cn	OP (DR)
DF	X4				D1	D2	D3	Dn	OP (DF)
VF	X5				E1	E2	E3	En	OP (VF)
C/P	X6				F1	F2	F3	Fn	OP (C/P)

Note:
For single indicator for each criterion, the Overall Performance value for each criterion is calculated as follows:

7. OP (Q) = A1*M1 + A2*M2 + A3*M3 +.....+ An*Mn
8. OP (DLT) = B1*M1 + B2*M2 + B3*M3 +.....+ Bn*Mn
9. OP (DR) = C1*M1 + C2*M2 +C3*M3 +.....+ CN*Mn
10. OP (DF) = D1*M1 + D2*M2 + D3*M3 +.....+ Dn*Mn
11. OP (VF) = E1*M1 + E2*M2 + E3*M3 + ...+ En*Mn
12. OP (C/P) = F1*M1 + F2*M2 + F3*M3 +.....+Fn*Mn

Case Two: For multiple indicators for each criterion

Criterion	Weight of Importance of each Criterion	P. M.	P. I.	Unit	Mach1	Mach2	Mach3	Mach(n)	Overall Performance
Weight of Importance of machine					M1	M2	M3	Mn	
Q	X1				A1	A2	A3	An	OP (Q)
	X2				B1	B2	B3	Bn	
DLT	X3				C1	C2	C3	Cn	OP (DLT)
	X4				D1	D2	D3	Dn	
DR	X5				E1	E2	E3	En	OP (DR)
	X6				F1	F2	F3	Fn	
DF	X7				G1	G2	G3	Gn	OP (DF)
	X8				H1	H2	H3	Hn	
VF	X9				I1	I2	I3	In	OP (VF)
	X10				J1	J2	J3	Jn	
C/P	X11				K1	K2	K3	Kn	OP (C/P)
	X12				L1	L2	L3	Ln	

Note:

For multiple indicators for each criterion, the Overall Performance value for each criteria is calculated as follows:

1. OP (Q) = [(A1*M1 + A2*M2 + A3*M3 +.....+ An*Mn) * X1] + [(B1*M1 + B2*M2 + B3*M3 +.....+ Bn*Mn) * X2]
2. OP (DLT) = [(C1*M1 + C2*M2 +C3*M3 +.....+ CN*Mn) * X3] + [(D1*M1 + D2*M2 + D3*M3 +.....+ Dn*Mn) * X4]
3. OP (DR) = [(E1*M1 + E2*M2 + E3*M3 + ...+ En*Mn) * X5] + [(F1*M1 + F2*M2 + F3*M3 +.....+Fn*Mn) * X6]
4. OP (DF) = [(G1*M1 + G2*M2 + G3*M3 +.....+ Gn*Mn) * X7] + [(H1*M1 + H2*M2 + H3*M3 + ...+Hn*Mn) * X8]
5. OP (VF) = [(I1*M1 + I2*M2 + I3*M3 +.....+ In*Mn) * X9] + [(J1*M1 + J2*M2 + J3*M3 +.....+ Jn*Mn)* X10]
6. OP (C/P) = [(K1*M1 +K2*M2 + K3*M3 +.....+Kn*Mn) * X11] + [(L1*M1 + L2*M2 + L3*M3 +.....+Ln*Mn) * X12]

Section 18: Current Facility and Machine (Group) SWOT Analysis

Aim: Identify the Strengths, Weaknesses, Opportunities and Threats of the current facility and machine (group)

Description: The PFM SWOT analysis is a link between manufacturing system improvement objectives and production facilities management. The purpose is to understand the Strengths, Weaknesses, Opportunities and Threats of the existing facilities and equipment management so as to identify the action items in the improvement plan. The analysis form is composed of category, feature and reason. In order to build up a consensus in the improvement approach, it is better to aggregate the management, functional, and operation levels meet together to gain a comprehensive assessment. Some typical definitions of them are provided for reference.

Worksheet 18

Strengths: Those activities, systems, technologies, procedures which the company does uniquely well.

Category	Feature	Reason
Management and Organisation	Management System	
	Employee	
Operations	Quality	
	Design Flexibility	
	Dependability	
	Technology	
Finance	Capital Structure	
	Accounting System	
Others	Image of Company	

Weaknesses: Those items (as strengths) which the company does not perform to an acceptable standard.

Category	Feature	Reason
Management and Organisation	Personnel Policies	
Operations	Delivery Lead Time	
	Capacity	
	Volume Flexibility	
	Location	
	Material Availability	
	Performance	
	Maintenance	

Opportunities: Those activities, events or potential events where the company might additionally exploit their competitiveness on the market.

Category	Feature	Reason
Economic		
Social and Political		
Market and Competition		
Products and Technology		
Others		

Threats: Those activities, (systems etc.) or events or potential events which might prevent the company reaching the corporate strategic objectives.

Category	Feature	Reason
Economic		
Social and Political		
Market and Competition		
Products and Technology		
Others		

Section 19: Facility and Machine (Group) Improvement Decision-Making Assessment

Aim: This section aims to analyse the possibility of replacement of each facility and machine (group) with respect to their current overall performance.

Description: This assessment is accomplished with the application of AHP (Analytic Hierarchy Process). The hierarchy of the decision-making is based on the hierarchical structure of the PFM PMS. A typical hierarchy is shown in Figure D.3.

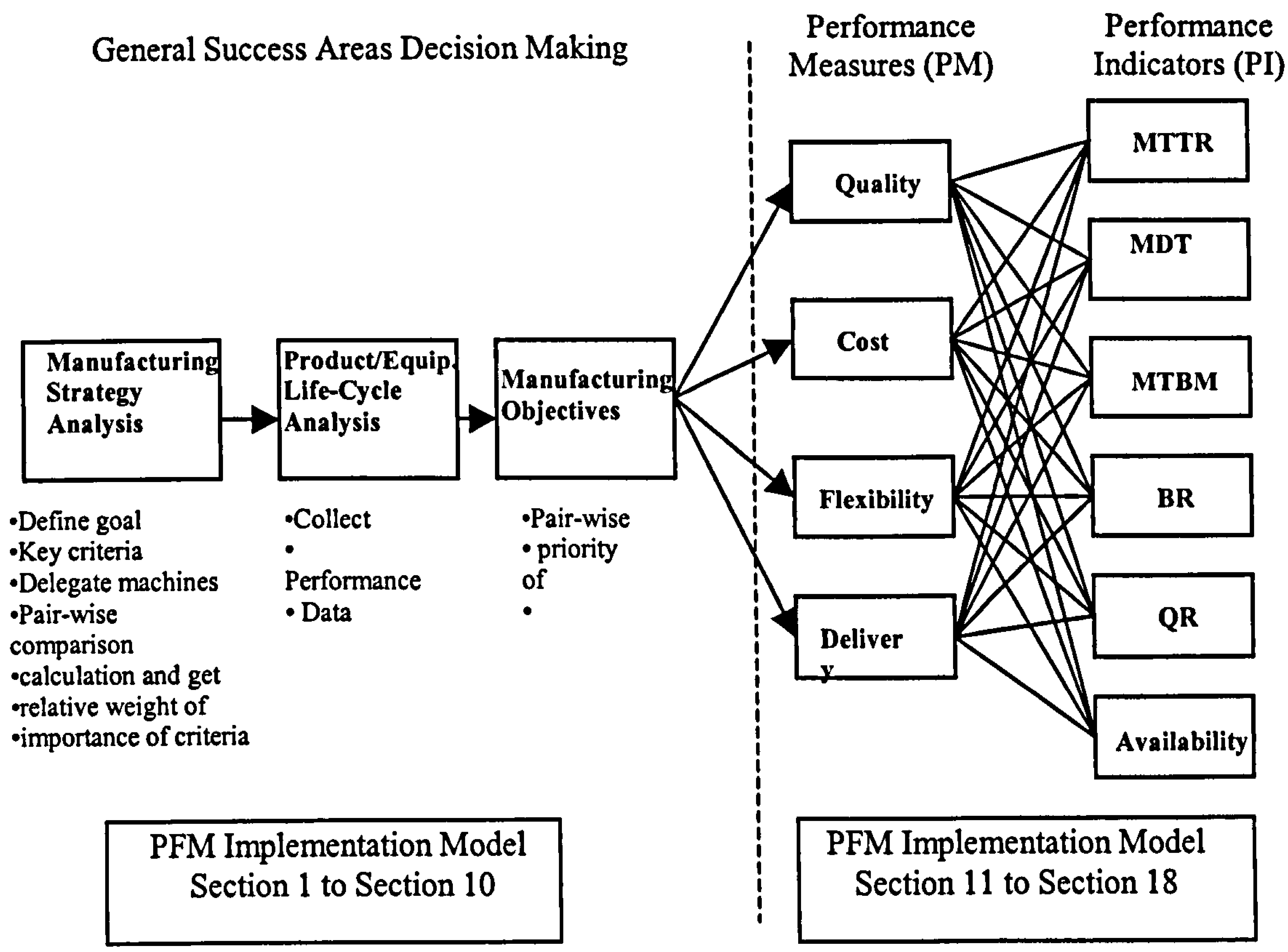


Figure D.3 Example Hierarchical Structure of Performance Measurement System for Decision-Making Assessment of Replacing Existing Facilities

The background data for the assessment come from the current facility and machine (group) performance analysis that is derived from section sixteen. The steps of the assessment are outlined as follows:

Step 1: Define PFM decision-making goal – The goal is usually defined as 'replacing current machine'.

Step 2: Define key criteria (PM & PI) and preference with respect to goal – This is accomplished with the definition of the hierarchical structure of the PFM PMS.

Step 3: Define delegate machines involved in decision-making assessment

Step 4: Derived priorities of each machine with respect to goal – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

Step 5: Pair-wise comparison of each delegate machinery with respect to each criterion – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

Step 6: Total pair-wise comparison of each delegate machine with respect to each criterion – This is accomplished by application of the calculation method of AHP to obtain the pair-wise value.

Section 20: Facility and Machine (Group) Performance Monitoring Project Establishment

Aim: Establishment of the performance monitoring project for each machine (group)

Description: The monitoring project is a follow-up of the improvement plan. In order to keep the consistency of the parameters to be monitored, the breakdown of each competitive criterion is derived from Worksheet 8. The contents of this linking table include the measures and indicators for the performance monitoring, the quantitative objectives of each indicator, the current achievement in each indicator, the time span of improvement plan, responsible party/personnel, and assessment period. The monitoring project is very important because it clarifies the target to be achieved and provides an opportunity to correct the deviation if necessary. All of the data in each table should be recorded and analysed periodically. Because of the dynamic characteristic of these data, the performance of the facilities and machine (group) will appear to be continuously changing.

Worksheet 20

Competitive Criteria	PM	PI	Objectives	Current	Time Span	Assessment Period	Responsible Personnel or Work Centre
Quality							
Delivery Lead Time							
Delivery Reliability							
Design Flexibility							
Volume Flexibility							
Cost							

Section 21: Performance Measurement System Comprehensiveness Balance Check

Aim: Cross checking the comprehensiveness of the improvement action plan

Description: The aim of the balanced scorecard check is to provide the assistance to cross check the comprehensiveness of the improvement plan and the feasibility of these performance monitoring measures. The design of this check list is based on the concept of balanced scorecard which was coined by Kaplan (1992). The project is checked from four perspectives: financial, customer, internal business and innovation and learning perspective. The contents to be checked include the goal, measures, relation between competitive criteria and strategic objectives.

Worksheet 21

Financial Perspective	How do we look to shareholder?	Competitive Criteria						Manufacturing strategic objectives										
Goals	Measures	Q	DLT	DR	DF	VF	C/P	C	F	P&T	V	S	Q	H	PPC	P&N	PM	0
Cost	Total Life Cycle Cost / Total Sales																	
Volume Flexibility	Overall Equipment Effectiveness																	
Cost	Net Present Value																	

Customer Perspective	How do customers see us?	Competitive Criteria						Manufacturing strategic objectives										
Goals	Measures	Q	DLT	DR	DF	VF	C/P	C	F	P&T	V	S	Q	H	PPC	P&N	PM	0
Delivery Lead Time	Promised Date Compliance																	
Quality	Not Right First Time																	
Delivery Reliability	Promised Quantity Compliance																	

Internal Business Perspective	What must we excel at?	Competitive Criteria						Manufacturing strategic objectives										
Goals	Measures	Q	DLT	DR	DF	VF	C/P	C	F	P&T	V	S	Q	H	PPC	P&N	PM	0
Productivity	Equipment Productivity																	
Capacity	Equipment Utilisation and Efficiency																	
Quality	Quality Rate																	

Innovation and Learning Perspective	Can we continue improvement and increase value?	Competitive Criteria						Manufacturing strategic objectives										
Goals	Measures	Q	DLT	DR	DF	VF	C/P	C	F	P&T	V	S	Q	H	PPC	P&N	PM	0
Supportability	Overall Equipment Effectiveness																	
Maintainability	Mean Time Between Maintenance																	
Reliability	Mean Time Between Failure																	

Section 22: Current Facility and Machine (Group) Performance versus Competitors' Performance Benchmark

Aim: Cross checking the performance of PFM from internal (company) and external viewpoint to ensure the comprehensiveness of the improvement project

Description: The aim of this benchmarking step is a double check to understand the survival ability and the opportunity of the company in the market. The method is to compare the company's current performance and targets to be improved with the competitor's current achievement in each competitive criterion. It is important to understand the competitors well:

1. To try to predict their future strategies.
2. To assess accurately competitor's probable reactions to internal strategic moves.
3. To estimate their ability to match own company in the quest for sustainable competitive advantage.

Worksheet 22

Criteria	Performance Measure (P.M.)	Performance Indicator (P.I.)	Objectives	Current Performance	Competitor's Performance
Quality					
Delivery Lead Time					
Delivery Reliability					
Design Flexibility					
Volume Flexibility					
Cost					

Section 23: Facility and Machine (Group) Performance Analysis (After 1st Improvement)

Aim: Establishment of the record of the historic performance data along with the operation for each facility and machine (group).

Description: The data to be recorded are chosen by the agreement of the management, functional and operational levels within the company. These data are provided for the performance gap analysis and for the reference of the execution of improvement plan. In order to be consistent with the strategic requirement, the items of the PM and PI are the same as those listed in Worksheet 16.

Worksheet 23

Performance Measures (PM)	Performance Indicators (PI)	Unit	Mach1	Mach2	Mach3	Mach …
Maintainability	Mean Time To Repair (MTTR)					
	Mean Corrective Time					
	Mean Preventative Maintenance Time					
	Mean Active Maintenance Time					
	Mean Time Between Replacement (MTBR)					
	Mean Time Between Maintenance (MTBM)					
	Mean Logistics Delay Time (MLDT)					
	Mean Administrative Delay Time (MADT)					
	Mean Maintenance Down Time (MDT)					
	Replacement Frequency (RF)					
Reliability	Breakdown Frequency (BR)					
	Failure Rate (FR)					
	Total Operating Hours					
	Mean Time Between Failure (MTBF)					
Labour	Maintenance Man hour per System Operating Hour (MMH/OH)					
	Maintenance Man Hour per Month (MMH/M)					
	Maintenance Man Hour per Maintenance Action (MMH/MA)					
	Total Products Produced					
Cost Factors	Maintenance Cost per System Operating Hour					
	Cost per Maintenance Action					
	Total Maintenance Cost					
	Total Maintenance Cost / Total Life Cycle Cost					
	Total Maintenance Man Hours					
Quality Factors	Quality Rate (QR)					
	Quality Product Numbers					
	Total Products Produced					
Flexibility Factors	Availability (Schedule Time – All Unplanned Time) / Schedule Time					
	Process Rate (Ideal Cycle Time / Actual Cycle Time) = Efficiency Ratio					
	Actual cycle Time = Total Working Hours + Total Maintenance Man Hours (Includes LDT and ADT)					
	Overall Equipment Effectiveness					

Section 24: Facility and Machine (Group) Performance Profiling (After 1st Improvement)

Aim: Establishment of the production facilities and equipment performance profiling data

Description: The aim of this profiling is to provide the gap analysis between the performance of facilities and the requirement of overall facilities after the improvement plan is executed. The procedure is the same as implemented in section seventeen. The overall performance of each machine (group) can be determined by six criteria: quality, delivery reliability, delivery lead time, design flexibility, volume flexibility, and cost. The performance of each criterion is an accumulated result from the performance of the sub-ordinary PM and PI. The relationship between these competitive criteria, PM, and PI is defined by the hierarchy of PFM PMS. The establishment of this profiling provides the data background for the gap analysis between the performance of facilities and the product requirements. The implementation process is the same as the analysis of the manufacturing system performance profiling in section five. The UV value calculation and polar diagram can also be used for the analysis in this section

Worksheet 24

Case one: For single indicator for each criterion

Competitive Criterion	Weight of Importance of each Criterion	P. M.	P. I.	Unit	Mach1	Mach2	Mach3	Mach(n)	Overall Performance
Weight of Importance of machine					M1	M2	M3	Mn	
Q	X1				A1	A2	A3	An	OP (Q)
DLT	X2				B1	B2	B3	Bn	OP (DLT)
DR	X3				C1	C2	C3	Cn	OP (DR)
DF	X4				D1	D2	D3	Dn	OP (DF)
VF	X5				E1	E2	E3	En	OP (VF)
C/P	X6				F1	F2	F3	Fn	OP (C/P)

Note:
For single indicator for each criterion, the Overall Performance value for each criterion is calculated as follows:

13. OP (Q) = A1*M1 + A2*M2 + A3*M3 +.....+ An*Mn
14. OP (DLT) = B1*M1 + B2*M2 + B3*M3 +.....+ Bn*Mn
15. OP (DR) = C1*M1 + C2*M2 +C3*M3 +.....+ CN*Mn
16. OP (DF) = D1*M1 + D2*M2 + D3*M3 +.....+ Dn*Mn
17. OP (VF) = E1*M1 + E2*M2 + E3*M3 + ...+ En*Mn
18. OP (C/P) = F1*M1 + F2*M2 + F3*M3 +.....+Fn*Mn

Case Two: For multiple indicators for each criterion

Criterion	Weight of Importance of each Criterion	P. M.	P. I.	Unit	Mach1	Mach2	Mach3	Mach(n)	Overall Performance
Weight of Importance of machine					M1	M2	M3	Mn	
Q	X1				A1	A2	A3	An	OP (Q)
	X2				B1	B2	B3	Bn	
DLT	X3				C1	C2	C3	Cn	OP (DLT)
	X4				D1	D2	D3	Dn	
DR	X5				E1	E2	E3	En	OP (DR)
	X6				F1	F2	F3	Fn	
DF	X7				G1	G2	G3	Gn	OP (DF)
	X8				H1	H2	H3	Hn	
VF	X9				I1	I2	I3	In	OP (VF)
	X10				J1	J2	J3	Jn	
C/P	X11				K1	K2	K3	Kn	OP (C/P)
	X12				L1	L2	L3	Ln	

Note:

For multiple indicators for each criterion, the Overall Performance value for each criteria is calculated as follows:

1. OP (Q) = [(A1*M1 + A2*M2 + A3*M3 +.....+ An*Mn) * X1] + [(B1*M1 + B2*M2 + B3*M3 +.....+ Bn*Mn) * X2]
2. OP (DLT) = [(C1*M1 + C2*M2 +C3*M3 +.....+ CN*Mn) * X3] + [(D1*M1 + D2*M2 + D3*M3 +.....+ Dn*Mn) * X4]
3. OP (DR) = [(E1*M1 + E2*M2 + E3*M3 + ...+ En*Mn) * X5] + [(F1*M1 + F2*M2 + F3*M3 +.....+Fn*Mn) * X6]
4. OP (DF) = [(G1*M1 + G2*M2 + G3*M3 +.....+ Gn*Mn) * X7] + [(H1*M1 + H2*M2 + H3*M3 + ...+Hn*Mn) * X8]
5. OP (VF) = [(I1*M1 + I2*M2 + I3*M3 +.....+ In*Mn) * X9] + [(J1*M1 + J2*M2 + J3*M3 +.....+ Jn*Mn)* X10]
6. OP (C/P) = [(K1*M1 +K2*M2 + K3*M3 +.....+Kn*Mn) * X11] + [(L1*M1 + L2*M2 + L3*M3 +.....+Ln*Mn) * X12]

Section 25: Product (Group) Requirement versus Facility and Machine (Group) Performance Gap Analysis

Aim: Establishment of the performance gap analysis between the product requirements and the key machine (group) and draw the chart of the gap analysis

Description: This section aims to analyse the performance gap between product (group) requirements and facility and machine (group) performance achievement after the improvement plan is implemented. If there were gaps, it means there is space for further improvement. The larger the gap means the more improvement action will be required in that criterion. The method is to compare the overall performance of facilities and machine (group) (data derived from section 23) and the requirements of the product (group) (data derived from section 3). The larger the gap is in a specified competitive criterion means there are more improvement actions should be required with respect to such criterion. The polar diagram can also be used for clear presentation of the deviation.

Worksheet 25

Competitive Criteria	Overall Machine (Group) Performance	Overall Product (Group) Requirements
	(Data derived from section 23)	(Data derived from section 3)
Quality		
Delivery Lead Time		
Delivery Reliability		
Design Flexibility		
Volume Flexibility		
Cost		

Section 26: Facility and Machine (Group) Improvement Plan Feasibility Analysis

Aim: The aim of this feasibility analysis is dealing with the appropriate choice of the improvement options in production facilities management.

Description: This section aims to assess the feasibility of the choice of the improvement options in production facilities management. The process is to assess the different possibility of maintaining, enhancing or replacing a current facility and machine (group) so as to match the production requirement. This analysis also discusses the relationship between these options with respect to the strategic requirements and policy decision-making areas. This analysis is based on identification of the weight of different options from the Production Facilities Management Decision-Making Assessment Quick Hit Table shown in Appendix I.

There are two typical implementation circles in a practical PFM operation. To assess the feasibility of establishing new facilities, enhancing and/or replacing current facilities, the PFM framework is implemented from section one to section 20. To assess the performance and feasibility of maintaining current facilities, the PFM framework is operated in a circle from section 11 to section 27. The difference is the former one should be initiated from an assessment of the strategic requirements and the latter one is concerned with achieving and supporting the current strategic requirements.

The process is to assess the different possibilities of maintaining, enhancing or replacing existing facilities and machine (group) so as to match the production requirements. This analysis also discusses the relationship between these options with the manufacturing strategic requirements shown through the assessment of 11 manufacturing system policy areas. This analysis is based on the identification of the weight of different options from the Production Facilities Management Decision-Making Assessment Quick Hit Table shown in Appendix I.

Worksheet 26

Manufacturing System Management Policy Area	Decision	Sub Decision	Production Facilities Management Option Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Facilities
Capacity					
Facilities					
Process & Technology					
Vertical Integration					
Supplier Relations					
Quality Systems					
Human Resources					
Production Planning & Control					
New Product Introduction & Scope					
Performance Measurement					
Organisation					

Part Two of the PFM Implementation Workbook

Example Test and Implementation Illustration

Example Worksheet 1:

Business/organisation classification	
A. Business Definition	
1. What is the business?	Processing and heat treatment
2. Who are the customers	Aircraft manufacturer,
3. Who are the competitors	Processing and heat treatment
B. Business structure	
1. Type of decentralisation (centralised, or decentralised)	Decentralised production line
2. Size of the company	110 employees
3. Hierarchical structure of the organisation (structural tree of the departments)	As shown in Figure D.1
C. Business Culture	
Ownership	Aero Industry Development Centre
D. Organisational behaviour	
1. Organisational process (job, project, batch, line, or continuous)	Project and job
2. Market position (growth, mature, new products, or decline)	Growth
E. Operating environment	
1. Business purpose	Aircraft manufacturer
2. Technology	Advanced technologies in aircraft manufacturing

Note:

1. The background data for this example is based on one of the interviewed companies in Taiwan.
2. The purpose of this example is to demonstrate the feasibility and utility of the designed table. However, the company is free to design the proper one for themselves.
3. A hierarchical structure of the interviewed company is shown in the following figure.
4. The hierarchical structure not only highlights the relations between the corporate, functional and operational levels but also demonstrates the hierarchical structure of the competitive criteria, performance measures and performance indicators.

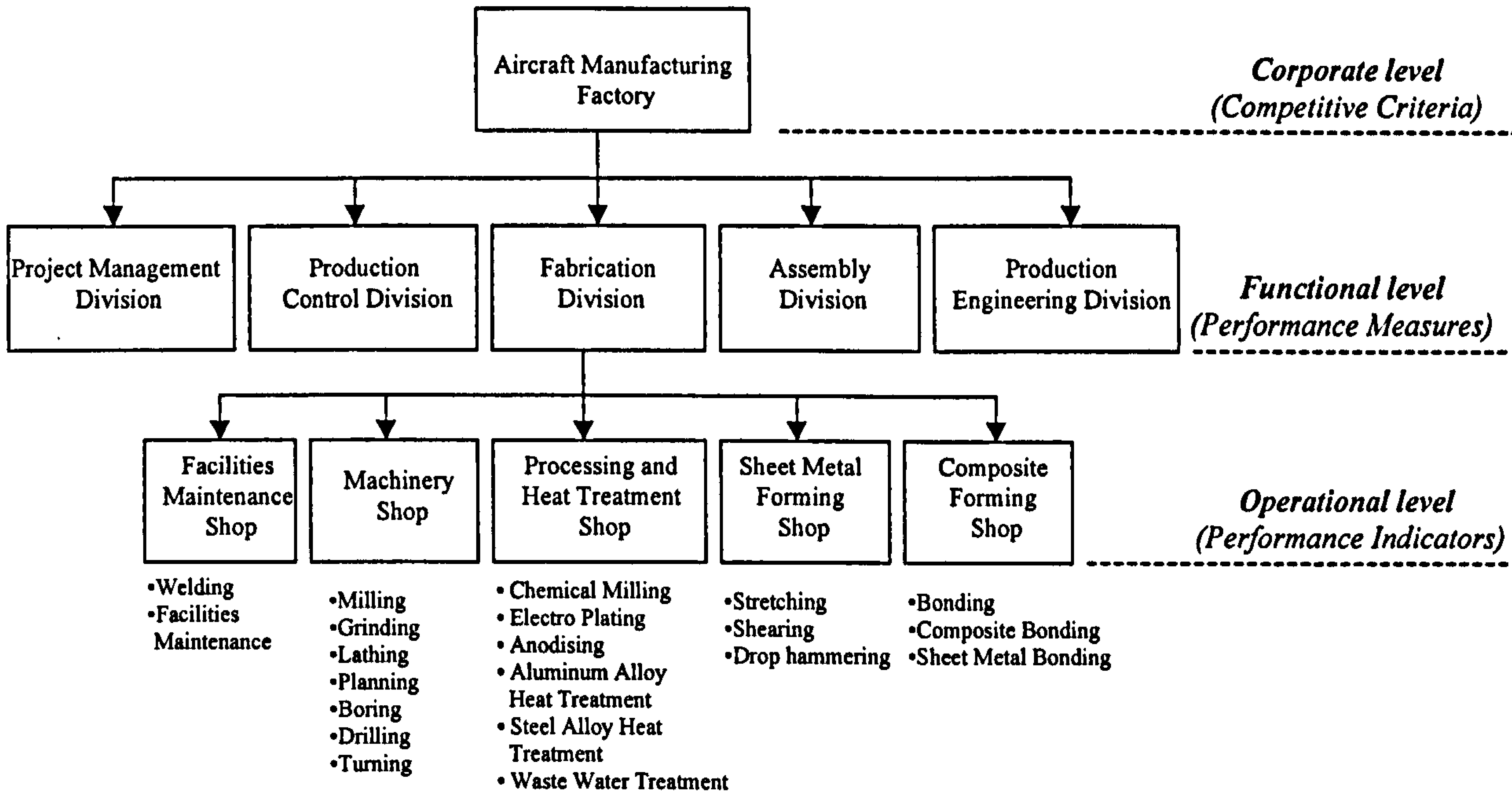


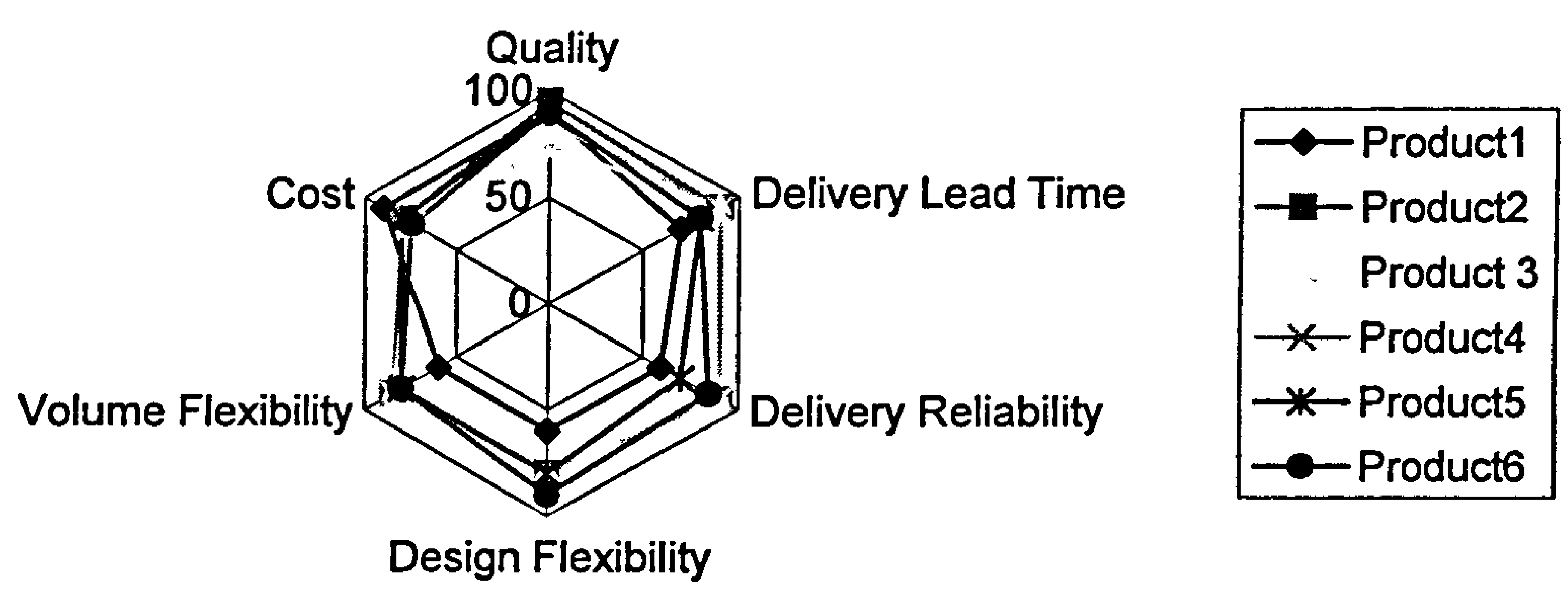
Figure D.1 Hierarchy of the Example Manufacturing Company

Worksheet 2 (Example) *Section2: Product (Group) Analysis*

Item	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Sub Total
Volume (units/yr)	6800	6340	9433	11708	34200	17533	86014
Sales (£/yr)	68000	76080	122633	175615	547200	368200	1357729
% of Sales	5.01	5.60	9.03	12.93	40.30	27.12	
% of Contribution	3.07	5.11	9.12	14.71	57.84	10.17	
Market Share (%)	24%	23%	35%	40%	39%	45%	
Growth Opportunities	Good	Good	Excellent	Excellent	Excellent	Very Good	
Degree of Innovation	Low	Low	High	High	High	Medium	
Life Cycle Stage	Decline	Decline	Production	Production	Production	Project-Oriented	
Principle Processes	Slitting	Machining	Machining	Threading	Sheet Forming	Machining	
		Assembly	Assembly	Painting	Painting	Assembly	
Materials	Steel	Casting	Casting	Aluminum	Aluminum	Stainless Steel	
Approximate Profit / Sales	40	41.67	38.46	40	46.88	57.14	
Typical Order Size	3400-6800	4000-12000	6000-10000	6000-11000	20000-30000	Project-Oriented	
Market Focus	Agriculture	Aero Industry	Aero Industry	Automobile	Automobile	Automobile	
Relative Importance	3.07	5.11	9.12	14.71	57.84	10.17	

Example Worksheet 3 *Section3: Product (Group) Market Analysis*

Competitive Criteria			Product Requirements				
	Product1	Product2	Product 3	Product4	Product5	Product6	Overall Requirement
Quality	90	95	75	85	90	90	88.17
Delivery Lead Time	70	90	90	90	80	80	82.60
Delivery Reliability	60	90	90	90	70	85	77.02
Design Flexibility	60	80	80	80	80	90	80.42
Volume Flexibility	60	85	85	85	80	80	80.85
Cost	90	80	75	75	80	75	78.62
Relative Importance of Product	3.07	5.11	9.12	14.71	57.84	10.17	

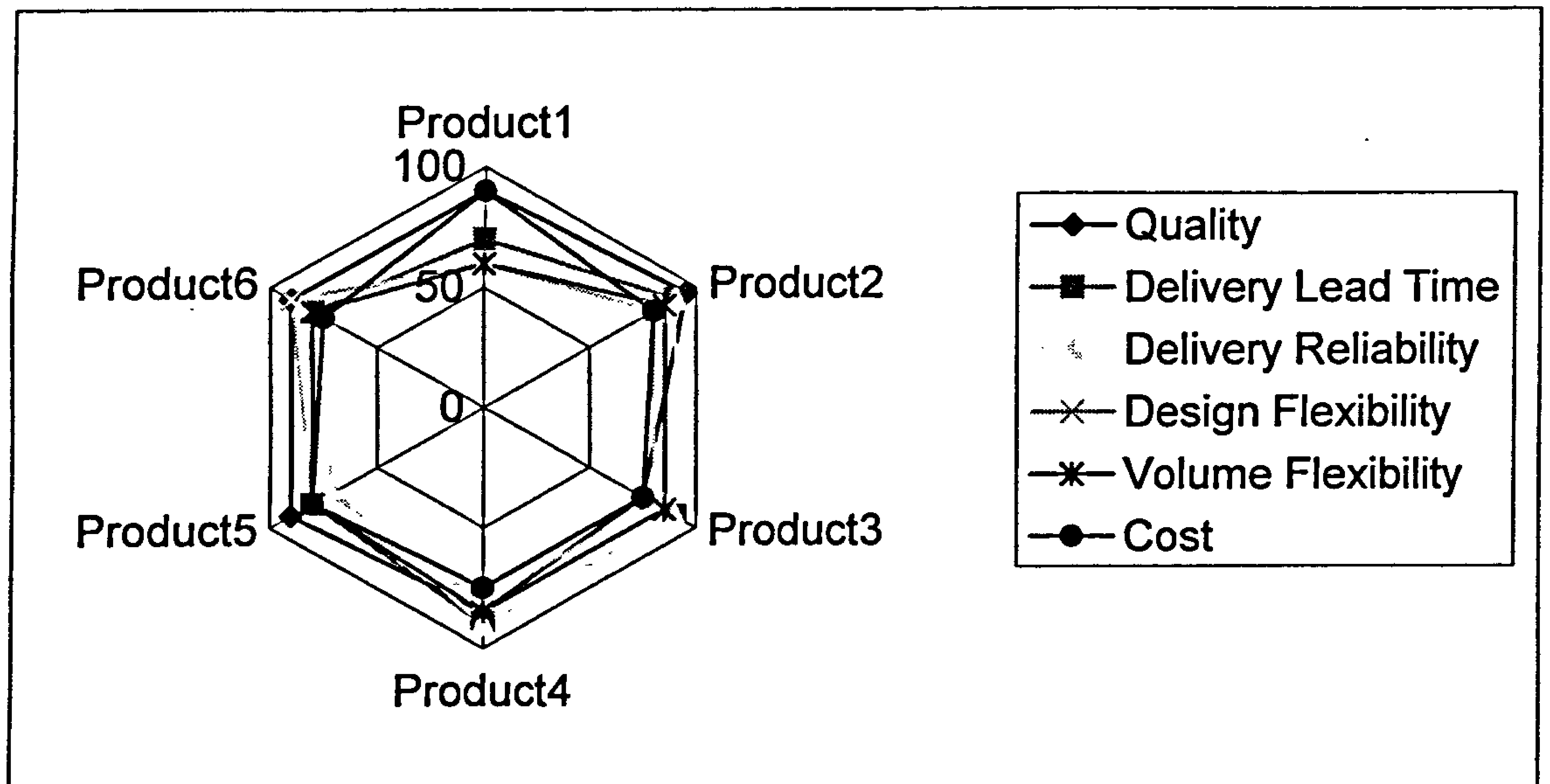


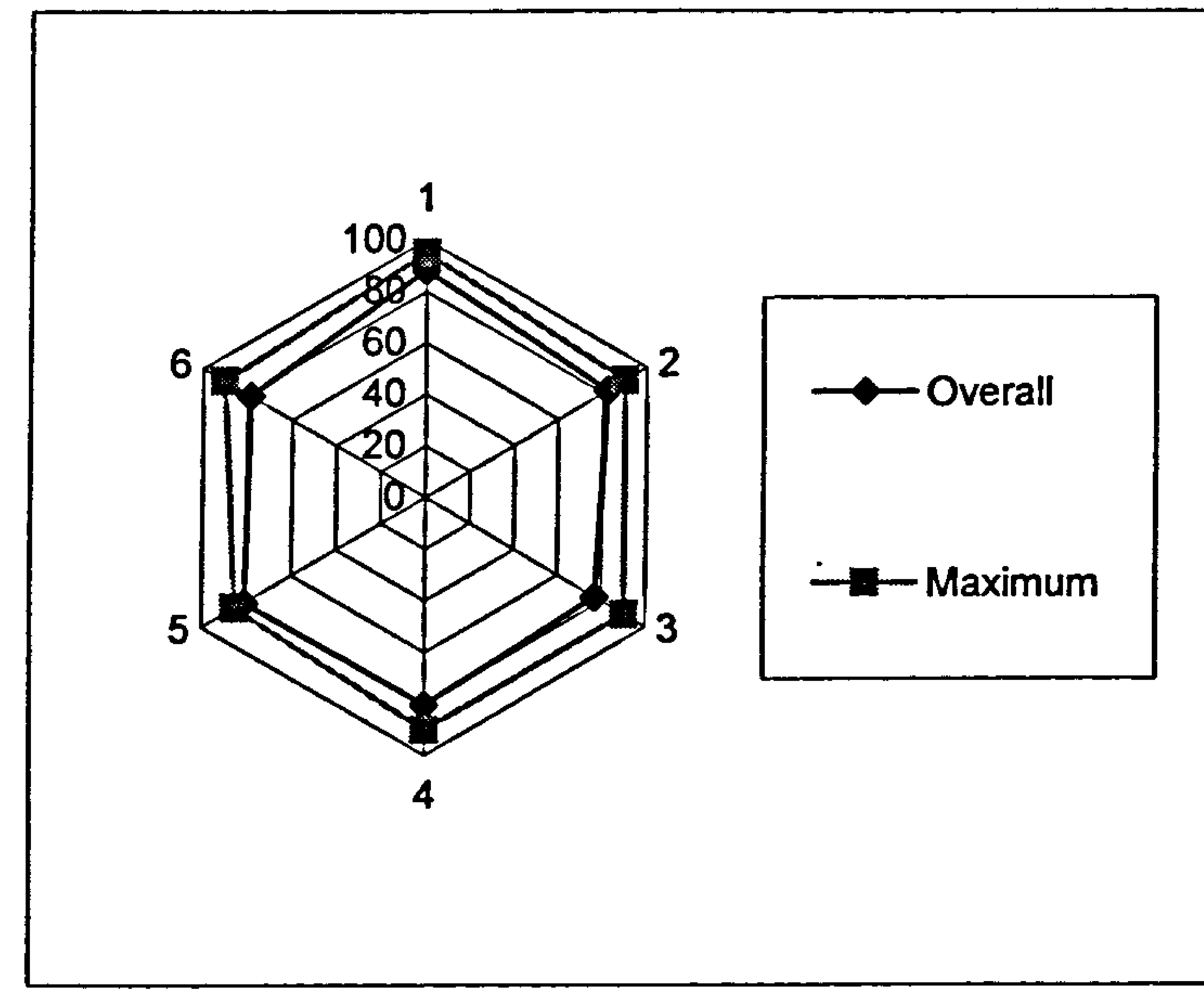
Analysis:

1. From the customer viewpoint, quality and delivery lead time of the product are the most satisfactory.
2. From the customer viewpoint, delivery reliability and cost of the products are the least satisfactory.
3. It is recommended that all of the management effort should work on activities which are related to improvement of delivery reliability and cost of the supply of the products.

Example Worksheet 4 *Section 4: Product (Group) and Performance Requirements Profiling*

Product	Product1	Product2	Product3	Product4	Product5	Product6	Overall	Maximum	Deviation	Improvement
Requirements							Requirement	Requirement		Priority
Quality	90	95	75	85	90	90	88.17	95	6.83	5
Delivery Lead Time	70	90	90	90	80	80	82.60	90	7.40	4
Delivery Reliability	60	90	90	90	70	85	77.02	90	12.98	1
Design Flexibility	60	80	80	80	80	90	80.42	90	9.58	3
Volume Flexibility	60	85	85	85	80	80	80.85	85	4.15	6
Cost	90	80	75	75	80	75	78.62	90	11.38	2
Relative Importance of Product	3.07	5.11	9.12	14.71	57.84	10.17				



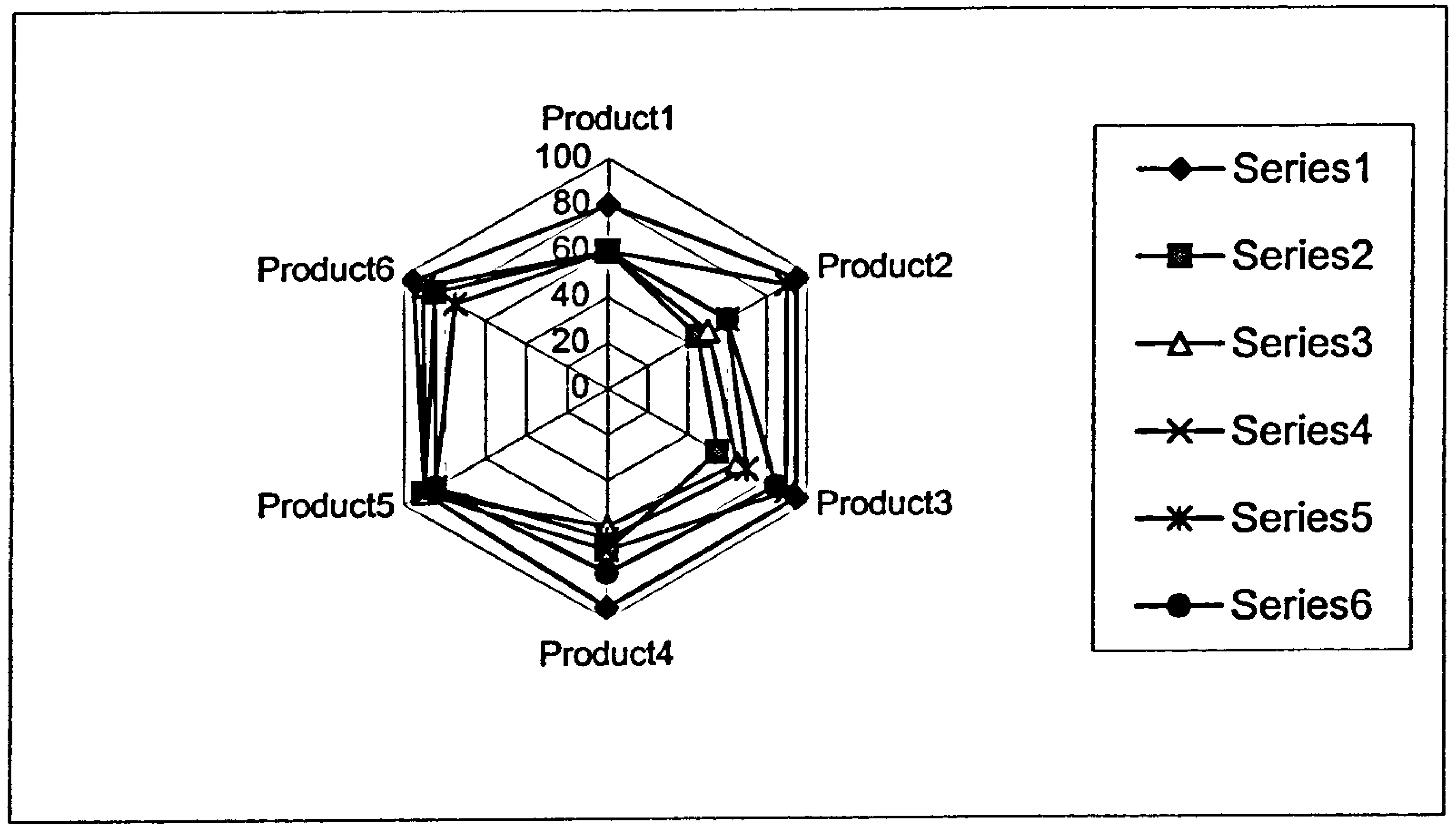


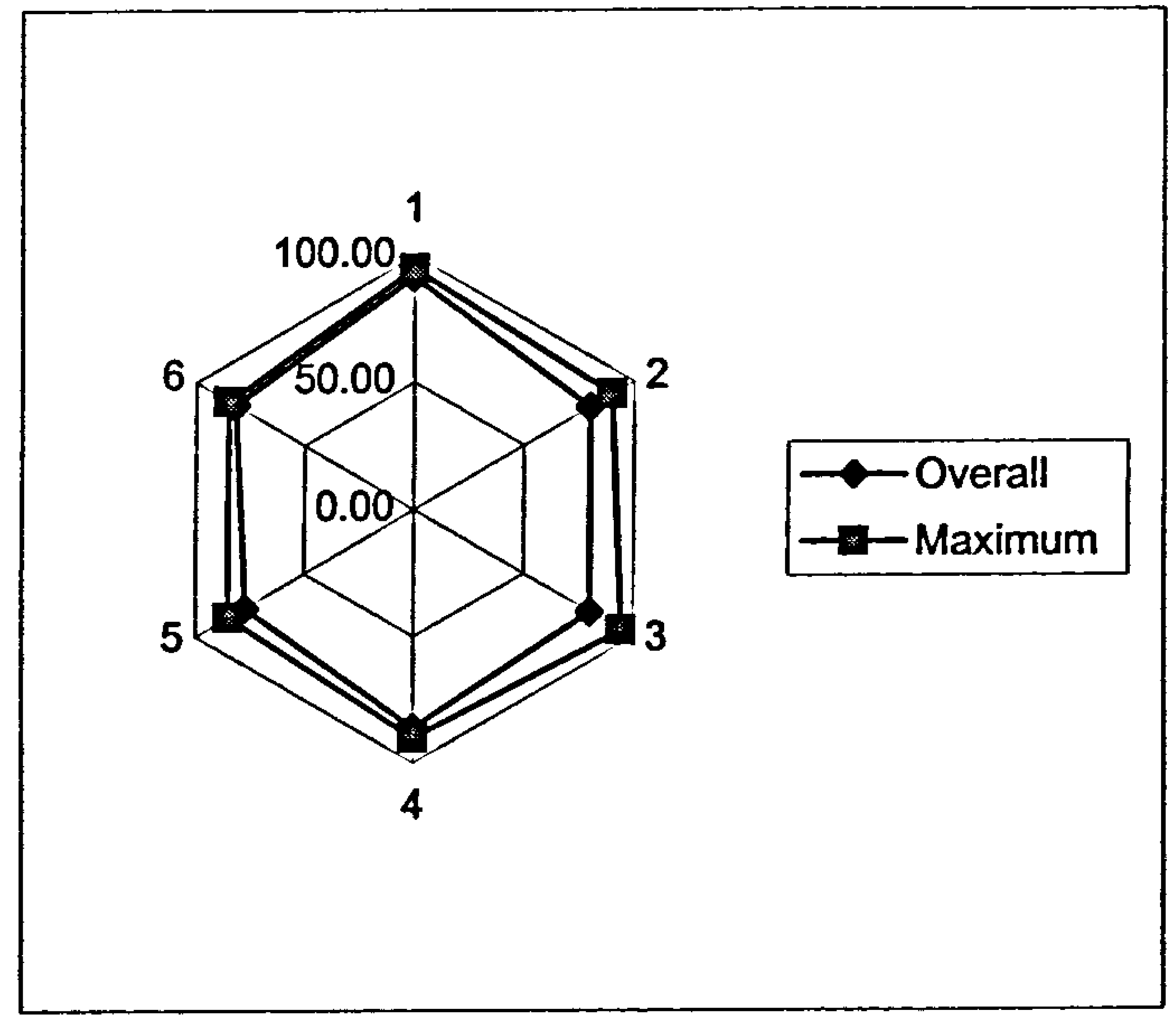
Analysis:

1. From the customer viewpoint, quality and delivery lead time of the product are the most satisfactory.
2. From the customer viewpoint, delivery reliability and cost of the products are the least satisfactory.
3. It is recommended that all of the management effort should work on activities which are related to improvement of the delivery reliability and cost of the supply of the products.

Example Worksheet 5 *Section 5: Manufacturing System Performance Profiling*

Product	Product1	Product2	Product3	Product4	Product5	Product6	Overall	Maximum	Deviation	Improvement
Requirements							Performance	Performance		Priority
Quality	80	95	95	95	90	95	91.67	95	3.33	5
Delivery Lead Time	60	45	55	70	90	85	80.16	90	9.85	2
Delivery Reliability	60	50	65	60	90	90	80.36	95	14.64	1
Design Flexibility	60	90	90	70	90	90	86.16	90	3.85	4
Volume Flexibility	60	60	70	65	85	75	77.65	85	7.35	3
Cost	60	60	85	80	85	85	82.24	85	2.76	6
Relative Importance of Product	3.07	5.11	9.12	14.71	57.84	10.17				



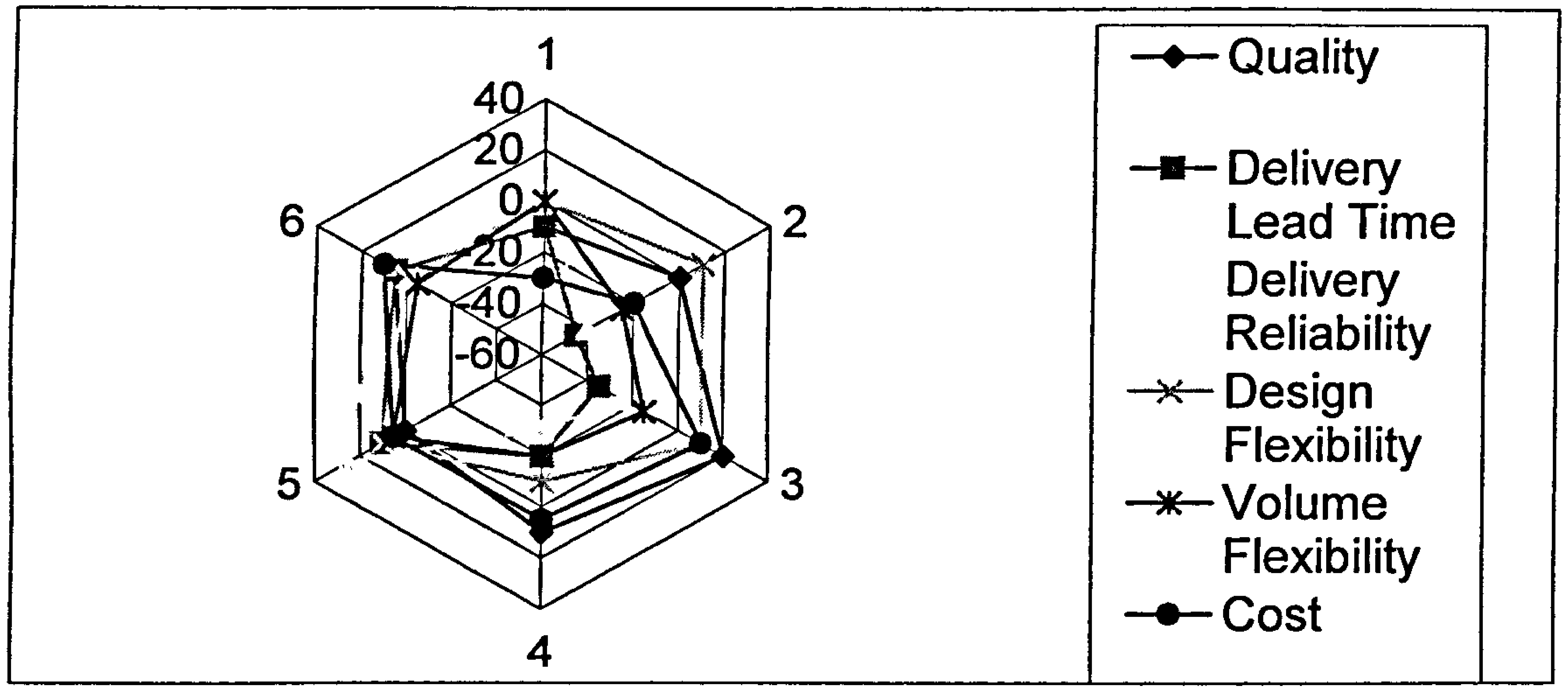


Analysis:

1. From the internal survey, the performance of the integrated manufacturing system in achieving the competitive criteria of quality and cost are the most satisfactory.
2. From the internal survey, the delivery lead time and delivery reliability are the least satisfactory inside the manufacturing system which means all of the effort of the management should work on the improvement related to these two criteria.

Example Worksheet 6 Product Requirement / Manufacturing Performance Gap Analysis

Requirements	Product1	Product2	Product3	Product4	Product5	Product6	Overall Gap Statistic	Improvement Priority
Quality	-10	0	20	10	0	5	25	6
Delivery Lead Time	-10	-45	-35	-20	10	5	-95	1
Delivery Reliability	0	-40	-25	-30	25	10	-60	2
Design Flexibility	0	10	10	-10	10	0	20	5
Volume Flexibility	0	-25	-15	-20	5	-5	-60	3
Cost	-30	-20	10	5	5	10	-20	4
Relative Importance of Product (Group)	3.07	5.11	9.12	14.71	57.84	10.17		



Analysis:

1. From the gap analysis, the largest gap between the customer and internal manufacturing recognisation is the performance on delivery reliability and flexibility which means all of the effort of management related to these two criteria should be set as the highest priority to be improved.
2. The improvement plan is going to demonstrated in the following steps.
3. From the results, the gap between the product and manufacturing performance is different with respect to different product (group). This is because different product is made by different manufacturing system and the implementation process internally and also by different customers externally.
4. In this example, there is a need of the improvement in achieving the criteria of delivery lead time, delivery reliability, and volume flexibility due to the larger gap is happened in these three performance requirements.
5. From the overall gap statistic result, the final decision of the priority of the improvement plan related to each criteria can be made by the amount of the gap.

Example Worksheet 7: (Section 7: Identify Key Issues)

The aim of this step is to discuss the reasons why the gap between customer requirements and the performance of manufacturing is generated. The identifying process should be based on the results of Worksheet 6 (Section 6). The reasons why these issues occur are listed in Appendix E (Key Issue Quick Hit Table). By a combination of the user's experience and referring to this reference table, the key issues can be identified and some principle improvement objectives can be obtained sequentially.

Key Issues	Strategic Improvement Objectives	Priority to be improved	Relationship of the improvement to the competitive criteria					
			Q	DLT	DR	DF	VF	C/P
Inadequate capacity	Increase capacity	1		X	X		X	
Inadequate forecasting of demand	Improve forecasting techniques	2		X	X			X
Long lead time	Reduce set-up times	3		X	X			X
Long lead time	Improve inventory information	4		X	X			X
Long lead time	Simplify material flow	5		X	X			X
Long lead time	Increase workforce skill	6	X	X	X			X
Long lead time	Reassess subcontracting and supplier policies	7	X	X	X	X		

Analysis:

1. From the results of Worksheet 6 (Section 6), the key issues resulting in low performance of the criteria delivery lead time, delivery reliability, and volume flexibility are derived from the Key Issue Quick Hit Table and listed in the "key issue" column.
2. The result is going to be kept as a record of the key issue analysis and the strategic improvement objectives are generated sequentially to establish the improvement action.
3. The key point of this identification process is to find and record every issue. However, only keep an eye on a handful of issues ; the most important issues related to the problem area so as to encourage the achievement of the improvement plan. In this example, seven key issues are recommended to be improved.
4. The priority of the strategic improvement objectives will influence the competitive criteria and the relations illustrated.

Example Worksheet 8 (Section 8: Define Corporate Mission Statement)

Corporate mission statement
The mission of manufacturing is to achieve stable delivery reliability of products. This will be done without sacrificing our high standards for quality or service to the customer. We will pursue the latest process, technology and a people based competitive advantage in order to be the most reliable product manufacturer.

Note:

1. The corporate mission statement states a purpose for manufacturing and a priority among strategic objectives. It is derived from the business background, product (group) and manufacturing system performance gap analysis, and the key issue identification.
2. Usually, the mission statement is quite broad and stated in general terms. It normally does not contain any numbers or specific objectives.
3. The corporate mission statement is the highest corporate strategic principle of the company. This statement should define the priority of corporate competitive criteria which can be utilised as the decision-making basis of investment in the future.
4. In this example, this statement provides a sense of priority – delivery reliability is being stressed. Also, the delivery reliability objective is stated relative to the competition in order to put things into perspective. A general indication is also given of how the objectives will be achieved – through process and people.
5. Delivery reliability is of course not the only thing that could be stressed by manufacturing in a mission statement. Other possibilities include: quality, service, flexibility, fast growth of new product introduction, short circle time or a combination of these. What is being stressed will generally follow the business strategy.

Example Worksheet 9: (Section 9: Define Strategic Aims)

Corporate Competitive Criteria / Key Issues / Manufacturing Strategic Aims Table

Corporate Competitive Criteria	*Key Issues*	*Manufacturing Strategic Aims*
Cost	• Inadequate forecasting of demand • Long lead time	• Accurate and efficient collection of manufacturing cycle times and all associated manufacturing costs including material and subcontracted services • Accurate and efficient machine tool performance monitoring • Improved method for the preparation of quotations through historical information of similar parts • Costing implications of splitting and joining batches
Quality	• Long lead time	• Offer consistently low defect rates • Quality standards to be improved above that of the competitors, thus safe guarding quality reputation • Accommodate customer quality requirements in an efficient and cost effective way • Reduce machine tool downtime while waiting for inspection of first off • Offer consistently low defect rates
Flexibility	• Long lead time	• Make rapid change in design and variation • Promotion of information availability throughout the manufacturing process • Promotion of system integration within the organisation • Promotion of integration between customers and suppliers • Promotion of information sharing between customers and suppliers • Improvement of small batch handling through set up time reduction • Improvement of small batch handling through reduction of programming prove-out time
		• Introduce new products quickly • Communication between customer and supplier • Integration information exchange between designer and manufacturing
	• Inadequate capacity	• Offer optimised equipment utilisation • Maximise facilities utilisation

Corporate Competitive Criteria	*Key Issues*	*Manufacturing Strategic Aims*
Delivery	• Inadequate capacity • Inadequate forecasting of demand • Long lead time	• Improve facilities management • Make dependable delivery promises • Improve delivery reliability and predictability • Establish accurate standard times • Create stability • Improve accuracy of information loaded into scheduling system • Eliminate time wasting • Reduce production lead time to less than that of competitors • Reduce prototyping lead time to less than that of competitors • Encourage customers to provide any design changes via CAD • Encourage customer-supplier information exchange – EDI • Improve the link between shop floor and production planning and control • Communication between customer and supplier

Example Worksheet 10: (Section 10: Identify Improvement Action Plan)

Policy Area	*Improvement Action Items*
Capacity	• Increase capacity through equipment enhancement • New equipment and new facilities procurement
Facilities	• Re lay-out plant • Precision maintenance records • Periodical assessment
Process and Technology	• Establish "Tiger Team" to solve emergency equipment breakdown • Improve fast changeover and multiple purpose tooling design • Increase regularity of improvement activities • Standards for recording data • Improve man-machine interface • Standardise equipment operational procedure • Parts and tools maintenance
Vertical Integration	• Integrate logistic support • Improve supply chain effectiveness
Supplier Relations	• Closer relationship with sub-contractor and parts supplier
Human Resources	• Multiple skilled training • Increase the operation interchange ability • On-job training • Implementation of license certification • Increase the operators' equipment competence
Quality Systems	• Autonomous maintenance education and training programme
Production Planning and Control	• Implement spare part inventory policy • Precision EOQ (Economic Order Quantity) re-order level • Close communication with capacity estimation • Planning and control • Improve preventative maintenance and condition monitoring • Implement parts pull system
New Product Introduction and Scope	• Close communication with designers • Standardise parts manufacturing
Performance Measurement	• Develop equipment performance monitoring system • Establish maintenance management system
Organisation	• Total organisational support • Establishment of maintenance circle

Example Worksheet 11: (Section 11: Capture Strategic Requirements and Identify Priority of Competitive Criteria)

Policy Decision-Making Areas	Policy (Strategic Requirements)	Competitive Criteria					
		Q	DLT	DR	DF	VF	C/P
Capacity	Develop decision-making support methodology in equipment management			x		x	x
Facilities	Relay-out the plant, decrease the work flow distance between equipment, adopt cellular manufacturing technology, TPM & RCM system introduction	x	x	x	x	x	
Process and Technology	Improve production engineering support, maximise equipment utilisation and efficiency, reduce set-up time, improve man-machine interface	x	x	x	x	x	x
Vertical Integration	Integrate logistic support, improve supply chain effectiveness & reliability, EDI introduction		x	x			x
Supplier Relations	Develop reliable subcontract suppliers, farm out volume bits, keep hi-technique internally	x		x			x
Human Resources	Develop job skills, increase quality concern, recruit qualified staff, enhance on-job and pre-job training, absenteeism control	x			x	x	x
Quality System	Establish quality programme, SPC introduction, ISO 9000 series certification, quality circle establishment, manufacturing processes' documentation, in process inspection, QFD & FMECA application	x		x			x
Production Planning and Control	MRPII system introduction, ERP system introduction, reduce inventory, simplify material flow, improve capacity planning, Kanban implementation		x	x		x	x
New Product Introduction and Scope	Concurrent engineering application, design for manufacturing, CAD/CAM		x		x		x
Performance Measurement	Develop performance measurement system	x	x	x	x	x	x
Organisation	Total organisation support, MIS development, ERP system introduction	x	x	x	x	x	x
Analyse sub total	If each "x" indicate score of "20"	140	140	180	120	140	200
Priority of the competitive criteria		3	4	2	6	5	1

Note:

1. Notation:

    1) Q = Quality
    2) DLT = Delivery Lead Time
    3) DR = Delivery Reliability
    4) DF = Design Flexibility
    5) VF = Volume Flexibility
    6) C/P = Cost / Price
    7) TPM = Total Productive Maintenance

8) RCM = Reliability Centred Maintenance
9) EDI – Electric Data Interchange
10) SPC = Statistical Process Control
11) MRPII = Material Resource Planning
12) ERP = Enterprise Resource Planning
13) QFD = Quality Function Deployment
14) FMECA = Failure Mode and Effect Cause Analysis
15) MIS = Management Information System

2. Analysis:

1) From the results in this example linking table, the relationship between policy area and the competitive criteria is identified. The more "x" it has in the policy area means the more important of the policy area in achieving the corporate strategy. In this example, the strategic objectives in the policy areas of "Process and Technology", " Performance Measurement", "Organisation" are the most important ones to be accomplished. However, the Production Facilities Management is an integrated activity.
2) In this example, the priority of each competitive criterion is defined as well. The sum of the score of sub-total in each competitive criterion indicates the weight of importance it is. The priority distribution in this example is shown as C is the most important criterion, then is DR, Q, DLT,VF and DF is the least important one.

Example Worksheet 12: (Section 12: Identify Product Life Cycle Stage

Product (Group)		Product (Group) Life Cycle Stage					
Item	Product (Group)	Concept	Design and Development	Production	Decline	Rapid Decline	Relative Importance
1	Product 1				X		
2	Product 2				X		
3	Product 3			X			
4	Product 4			X			
5	Product 5			X			
6	Product 6			X (project)			

The product (group) life cycle data are derived from the product (group) analysis (section two).

		Existing Products		New Products				
Item	Capacity Requirement	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Sub Total
1	Production year (Present)	3.5	3.5	2	1.5	3.5	1.5	
2	Production year (Expected)	4	5.5	6.5	8	7.5	2	
3	Product life (Present/Expected)*100%	87.50	63.64	30.77	18.75	0.47	0.75	
4	Number required (pieces)	71400	93250	169800	252300	239400	26300	
5	Unit working hour (hrs/unit)	2.1	1.42	1.4	1.71	1.92	2.3	
6	Number of products produced	67500	67000	35100	33300	69700	11300	
7	Operating hours (used hrs)	141750	95140	49140	56943	133824	25990	
8	Unit working hour on machine 1 (hrs/unit)	0.14	0.31	0.25	0.18	0.30	0.00	
9	Unit working hour on machine 2 (hrs/unit)	0.14	0.31	0.44	0.41	0.43	0.33	
10	Unit working hour on machine 3 (hrs/unit)	0.14	0.47	0	0	0	0.72	
11	Unit working hour on machine 4 (hrs/unit)	0.14	0.31	0.27	0.38	0.32	0.42	
12	Unit working hour on machine 5 (hrs/unit)	0.14	0	0.27	0.37	0.45	0.33	
13	Unit working hour on machine 6 (hrs/unit)	0	0	0.66	0.37	0.42	0.50	
14	Total working hours on machine 1 (hrs)	10000	29370.079	42000	46415.243	71820	0	199605.32
15	Total working hours on machine 2 (hrs)	10000	29370.079	74872.441	102776.61	102942	8679	328640.13
16	Total working hours on machine 3 (hrs)	10000	44055.118	0	0	0	18936	72991.12
17	Total working hours on machine 4 (hrs)	10000	29370.079	45000	96145.861	76608	11046	268169.94
18	Total working hours on machine 5 (hrs)	10000	0	45000	92830.486	107730	8679	264239.4862
19	Total working hours on machine 6 (hrs)	0	0	112308.66	92830.486	100548	13150	318837.1476
20	Total working hours used on machine 1 (hrs)	9453.78	21102.36	8681.98	6126.1498	20910	0	66274.27
21	Total working hours used on machine 2 (hrs)	9453.78	21102.36	15477.17	13565.05	29971.00	3729.00	93298.36
22	Total working hours used on machine 3 (hrs)	9453.78	31653.543	0	0	0	8136	49243.32
23	Total working hours used on machine 4 (hrs)	9453.78	21102.36	9302.12	12689.88	22304.00	4746.00	79598.15
24	Total working hours used on machine 5 (hrs)	9453.78	0	9302.12	12252.3	31365	3729	66102.20
25	Total working hours used on machine 6 (hrs)	0	0	23215.75	12252.3	29274	5650	70392.05

Example Worksheet 13

Section 13: Capture Current Products and Facilities Situation

		Existing Products		New Products				
Item	Capacity Requirement	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Sub Total
26	Total products produced on machine 1 (pieces)	67500	67000	35100	33300	69700	0	272600
27	Total products produced on machine 2 (pieces)	67500	67000	35100	15039	69700	11300	265639
28	Total products produced on machine 3 (pieces)	67500	67000	0	0	0	11300	145800
29	Total products produced on machine 4 (pieces)	67500	67000	35100	33300	69700	11300	283900
30	Total products produced on machine 5 (pieces)	67500	0	35100	33300	69700	11300	216900
31	Total products produced on machine 6 (pieces)	0	0	35100	33300	69700	11300	149400
32	Total working hours required	149940	132415	237720	409374	459648	60490	1449587

Example Worksheet 14 *Section 14: Facilities and Machine (Group) Analysis*

Facilities spec. items	Relative Importance of each spec. item	Degree of each item
Original purchasing price (£)	0.3	High (40,000+)
		Medium (10,000 to 40,000)
		Low (less than 10,000)
Process type	for reference only	convential or non-convential
Precision	0.1	High (within 0.005 inch tolerance)
		Medium (within 0.010 inch tolence)
		Low (tolerance up to 0.100 inch)
Throughput time	0.05	Long
		Medium
		Short
Productivity	0.1	High
		Medium
		Low
Space required	0.025	Large
		Medium
		Small
Calibration requirement	0.05	High (out resource)
		Medium (self contained)
		Low (no command)
Expected service period	0.1	Long (over 10 years)
		Medium (5-10 years)
		Short (less than 5 years)
Maintainability	0.1	Complex (special support equipment & tools)
		Normal (typical tools and time)
		Easy (simple tools and time)
Operational capability	0.05	Non-manned (can be 24 hours)
		Manual (always need supervision)
Utility consumption	0.05	High
		Medium
		Low
Functional replaceability	0.05	Has alternative machine
		Unique machine
Weight of each machine		
Relative Importance		

Weight of degree of each item	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5	Machine 6
50			32,000	40,000	280,000	350,000
30		25,000				
20	9,000					
	conventional	conventional	CNC, 3-axis	CNC, 3-axis	CNC, 5-axis	CNC, 5-axis
50			X	X	X	X
30		X				
20	X					
20						
30		X				
50	X		X	X	X	X
50	X		X	X		X
30		X			X	
20						
50					X	X
30		X	X	X		
20	X					
50					X	X
30		X	X	X		
20	X					
50					X	X
30	X	X	X	X		
20						
50			X	X	X	X
30		X				
20	X					
60			X	X	X	X
40	X	X				
50					X	X
30		X	X	X		
20	X					
20	X	X	X	X		
80					X	X
	26	29.25	43.25	43.25	48.75	52
	10.72	12.06	17.84	17.84	20.10	21.44

Example Worksheet 15 Performance Measure & Indicator Matrix Quick Hit Table

Quality	Delivery Lead Time	Delivery Reliability	Design Flexibility	Volume Flexibility	Cost / Price	Performance Measure	Mean Corrective Time	Breakdown Frequency	Mean Active Maintenance Time	Mean Time Between Maintenance (MTBM)	Mean Time Between Replacement (MTBR)	Mean Down Time (MDT)	Mean Time Between Failure (MTBF)
Criteria							Indicator						
	P	P	2	2		Maintainability	X	X	X	X	X	X	
P			P		2	Reliability							X
2		P		2	p	Availability		X					
		2		2	P	Labour							
		P	2	2	2	Supportability		X		X	X		
2			P	2	2	Skill							
2		P	2		P	Tooling							
P		2				Calibration		X					
	2	P	P	2	2	Capacity		X					
	2	P	2		2	Construction							
2	2		P			Documentation		X					
			2	2		Dimension							
	2	2		2	2	Space utilisation							
		P		2	P	Productivity		X					
		2		2	2	Lay-out							
		2			2	Location							
					P	Cost Factors		X					
					P	Safety							
P	2	P			P	Quality Factors							
2		P			2	Delivery Achievement		X					

Performance Measure	Set-up Times	Tool Changeover Time	Throughput Time	Failure Rate	Overall Equipment Effectiveness (OEE)	Maintenance Man Hours per System Operating hour (MMH/OH)	Maintenance Man Hours per cycle of System Operation(MMH/cycle)	Maintenance Man Hours per Month (MMH/month)	Maintenance Man Hours per Maintenance Action(MMH/MA)	Utilisation	Equipment Performance Effeciency	Payback period	Maintenance Cost per System Operating Hour
Maintainability						X	X	X	X				X
Reliability				X									
Availability	X	X			X	X	X				X		
Labour	X	X	X			X	X	X	X	X			
Supportability	X										X		X
Skill	X		X										
Tooling		X								X			
Calibration													
Capacity	X	X	X						X	X	X		
Construction													
Documentation	X		X							X	X		
Dimension													
Space utilisation										X			
Productivity	X	X	X							X	X		
Lay-out													
Location													
Cost Factors	X		X						X		X	X	X
Safety													
Quality Factors													
Delivery Achievement	X		X										

Performance Measure	Maintenance Cost per Month	Maintenance Cost per Year	Total maintenance Cost / Equipment Replacement Cost	Total Maintenance Cost / Total Life Cycle Cost		Quality Rate	Productivity	Net Present Value (NPV)	Overall Availability	Not Right First Time	Stock Turns	Promised Date Compliance	Value Added per Person
Maintainability	X	X	X	X							X		
Reliability						X							
Availability						X	X		X		X		
Labour							X						
Supportability	X	X	X	X		X	X		X		X	X	
Skill													
Tooling											X		
Calibration						X							
Capacity						X	X						
Construction													
Documentation						X			X			X	
Dimension													
Space utilisation													
Productivity							X				X		
Lay-out													
Location													
Cost Factors	X	X	X	X		X	X	X			X	X	X
Safety													
Quality Factors										X		X	
Delivery Achievement												X	

Performance Measure	Floor Space Utilisation	New Product Introduction Time	Utility Consumption	
Maintainability				
Reliability				
Availability				
Labour				
Supportability				
Skill		X		
Tooling		X		
Calibration				
Capacity	X	X		
Construction	X			
Documentation	X	X		
Dimension	X			
Space utilisation	X			
Productivity	X	X		
Lay-out	X			
Location	X			
Cost Factors	X	X		
Safety				
Quality Factors				
Delivery Achievement		X		

Notes:

1. There are two goals in utilisation this table.

- For existing equipment, the performance measure which is assessed in this table can indicate the present operation in its life cycle of each equipment.
- For new equipment acquisition, these measures are important decision-making factors in biding. In the following operation stage after acquisition, these factors are required to build up maintenance plan.

2. **Reliability** – Reliability can be defined as the probability that a system or product will perform in a satisfactory manner for a given period of time when it is used under specified operating conditions. The measures to be concerned in reliability prediction are:

<1> **Failure rate** (λ): λ is expressed as:

$$\lambda = \frac{Number\ of\ Failures}{Total\ Operating\ Hours}$$

<2> Reliability is also used as a measure of the frequency of downtime, or **Mean Time Between Failures (MTBF)**. It is determined by:

$$\mathrm{Re}liability = MTBF = \frac{Total\ operating\ time}{Number\ of\ failures}$$

$$\mathrm{Re}liability = MTBF = \frac{Total\ operating\ cycles\ (km, tons)}{Number\ of\ failures}$$

3. **Maintainability** – Maintainability is the measure of the ability to make equipment available after it has failed. Some of the typical measures related to maintainability prediction are:

<1>**Mean corrective time** ($\overline{Mct}$)**:** Each time that a system fails, a series of steps are required to repair or restore the system to its full operational status. The mean corrective maintenance time ($\overline{Mct}$), or the mean time to repair (MTTR) which is equivalent is a composite value representing the arithmetic average of these individual maintenance cycle times.

$$\overline{M}_{ct} = \frac{\sum_{i=1}^{n} Mct_i}{n} = MTTR$$

Where Mct_i is the total active corrective maintenance cycle time for each maintenance action and "n" is the sample size.

<2>**Mean preventative maintenance time** ($\overline{Mpt}$): $\overline{Mpt}$ is the mean elapsed time to perform preventative or scheduled maintenance on an item, and it is expressed as:

$$\overline{M}pt = \frac{\sum (fpt_i)(Mpt_i)}{\sum fpt_i}$$

where fpt_i is the frequency of the individual (ith) preventative maintenance action in actions per system operating hour, and Mpt_i is the elapsed time required for the (ith) preventative maintenance action.

<3>**Mean active maintenance time**($\overline{M}$): $\overline{M}$ is the mean or average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance. It excludes logistics delay time (LDT) and administrative delay time (ADT) and is expressed as:

$$\overline{M} = \frac{(\lambda)(\overline{M}ct) + (fpt)(\overline{M}pt)}{\lambda + fpt}$$

where λ is the corrective maintenance rate or failure rate, and fpt is the preventative maintenance rate.

<4>**Maintenance downtime** (MDT): MDT constitutes the total elapsed time required (when the system is not operational) to repair and restore a system to full operating status, and/or to retain a system in that condition. MDT includes mean active maintenance time, logistics delay time (LDT), and administrative delay time (ADT).

<5>**Mean time between maintenance** (MTBM): MTBM is the elapsed time between maintenance actions (corrective and preventative maintenance) and can be expressed as:

$$MTBM = \frac{1}{1/MTBM_u + 1/MTBM_s}$$

where $MTBM_u$ is the mean interval of unscheduled (corrective) maintenance and $MTBM_s$ is the mean interval of scheduled (preventative) maintenance.

<6>**Mean time between replacement** (MTBR): MTBR is the mean time between item replacement and is a major parameter in determining spare-time requirements. A maintainability objective in system design is to maximise MTBR where feasible.

4. **Maintenance labour hour factors**: When considering measures of maintainability, it is necessary to consider labour-time elements as well. Typical labour-time factors are:
   <1> Maintenance man hours per system operating hours (MMH/OH)
   <2> Maintenance man hours per cycle of system operation (MMH/cycle)
   <3> Maintenance man hours per month (MMH/month)
   <4> Maintenance man hours per maintenance action (MMH/MA)
   <5> All mean values of these factors

5. **Maintenance cost factors**: Maintainability is directly concerned with the characteristics of system design that will ultimately result in the accomplishment of maintenance at minimising overall cost. There are some important cost-related criteria in the system design:

<1> Cost per maintenance action
<2> Maintenance cost per system operating hour
<3> Maintenance cost per month
<4> Maintenance cost per order
<5> The ratio of maintenance cost to total life-cycle cost

6. Availability factors : Availability is a measure of uptime, as well as the duration of downtime. The term availability is always used as a measure of system readiness, i.e. the degree, percent or probability that a system will be ready or available when it is required for use. The factors of availability are:

<1> Operational availability – Operational availability is the probability that a system or equipment when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. It is described as:

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Where the MTBM is the mean time between maintenance, the MDT is the mean maintenance downtime

<2> Overall Availability

$$Availability = \frac{Scheduled\ time - All\ unplanned\ time}{Scheduled\ time}$$

7. Overall Equipment Effectiveness – Overall Equipment Effectiveness is an overall measure that considers uptime, speed, and precision. It is measured as a product of:

$$Overall\ Equipment\ Effectiveness\ (OEE) = Overall\ availability * Process\ rate * Quality\ rate$$

8. Process rate – Process rate is a measure of the ability of the equipment to operate at a standard speed or cycle. It is calculated by:

$$Process\ rate = \frac{Ideal\ cycle\ time}{Actual\ cycle\ time}$$

9. Quality rate – Quality rate is a measure of the ability of the equipment to produce to a standard product quality. It is measured by:

$$Quality\ rate = \frac{Quality\ Product}{Total\ product\ produced}$$

10. NPV – Net Present Value, i.e. the net economic value of present equipment after estimated years

$$NPV = \left(\sum_{n=1}^{L} \frac{I_n - E_n}{(1+i)^n}\right) + \frac{S_L}{(1+i)^L}$$

where

NPV = *Net present value*

I_n = *Income for year n*

E_n = *Expenditure for year n*

i = *Discount rate*

L = *Life of equipment or number of years being considered*

S_L = *Sale or scrap value at end of life, i.e. year n*

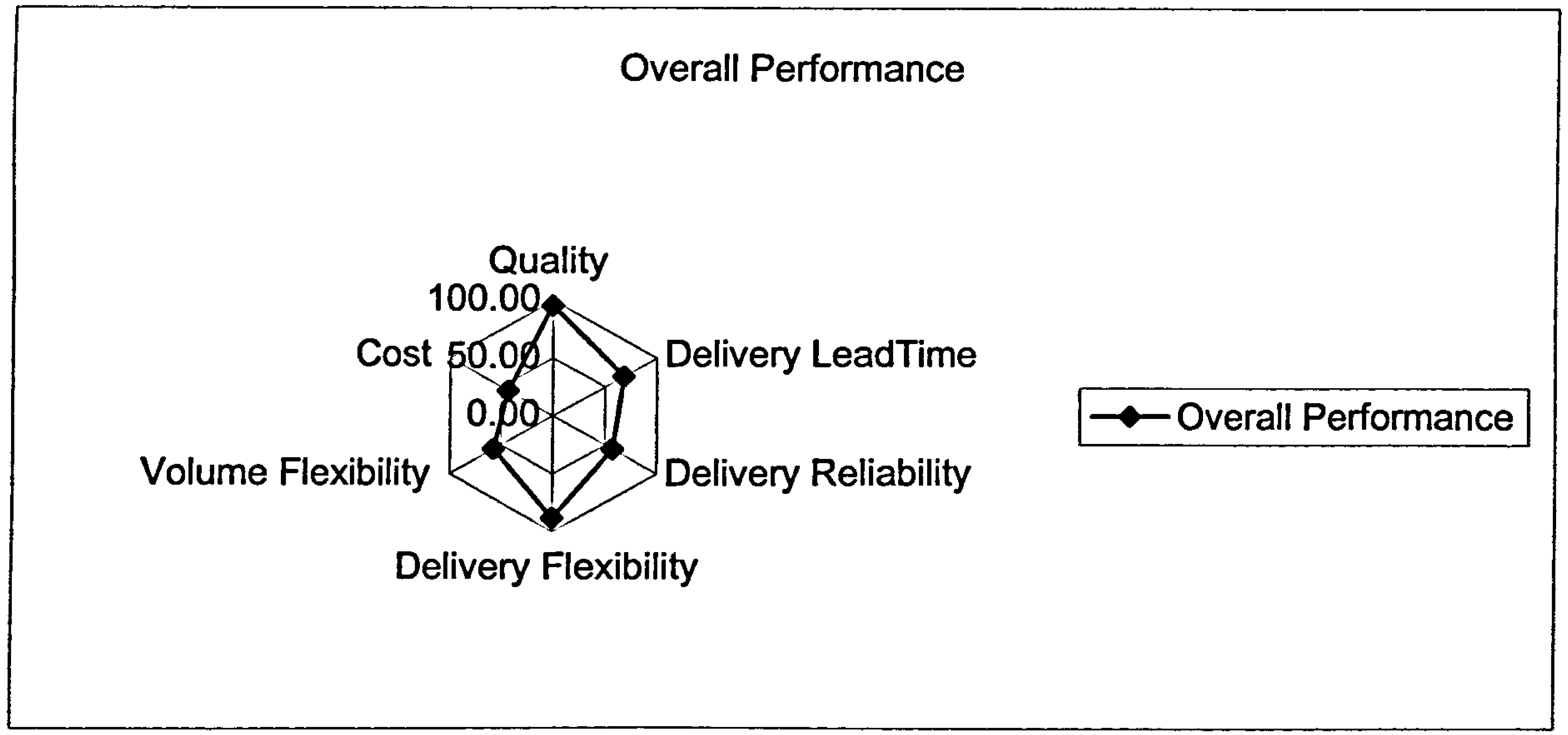
ExampleSection 16: Facilities and Machine (Group) Performance Analysis (Current)

Performance Measures (P.M.)	P.I. Item No.	Performance Indicators (P.I.)	Unit
Maintainability	1	MTTR (Mean Time To Repair)or (Mean Corrective Time)	hours
	2	Mean prevenTAtive maintenance time	hours
	3	Mean Active Maintenance Time	hours
	4	MTBR (Mean Time Between Replacement)	hours
	5	MTBM (Mean Time Between Maintenance)	hours
	6	MLDT (Mean Logistics Delay Time)	hours
	7	MADT (Mean Administrative Delay Time)	hours
	8	MMDT (Mean Maintenance Downtime, includING MLDT and MADT))	hours
	9	RF (Replacement Frequency)	times
Reliability	10	BR (Breakdown Frequency) or Number of failures	times
	11	Failure rate(Number of failures / total operating hours)	times/hr
	12	Total operating hours	hours
	13	MTBF (Mean Time Between failure)	hours
Maintenance	14	MMH/OH (Maintenance man hourS per System operating hr)	%
Labour	15	MMH/month (Maintenance man hourS per month)	hrs/mon
	16	MMH/MA (Maintenance man hourS per Maintenance action)	Hours
Cost	17	Maintenance cost per system operating hour	£/hr
	18	Cost per maintenance action	£
	19	Total maintenance cost	£
	20	Toatal maintenance cost / Total life cycle cost	%
	21	Total maintenance man hours (Exclude MLDT and MADT)	hours
	22	Total maintenance man hours (Include MLDT and MADT)	hours
Quality	23	Quality rate (Quality products / Total products produced)	%
	24	Quality product	pieces
	25	Total products produced	pieces
	26	Availability (Schedule time -All unplanned time) / Schedule time	%
	27	Process rate (Ideal cycle time / Actual cycle time) = Efficiency ratio	%
	28	Total Cycle Time =Total working hours + Total maintenance	hours
		man hours (Include MLDT andMADT)	
Flexibility	29	Capacity ratio (Actual hours worked / Budgeted standard hours)* 100%	%
	30	Working hours per day (A)	minutes
	31	Planned downtime per day (scheduled maintenance, meetings, etc) (B)	minutes
	32	Loading time per day = A - B	minutes
	33	Typical setup time per day (C)	minutes
	34	Typical adjustment time (D)	minutes
	35	Stoppage per day	minutes
	36	Operating time per day = A-B-C-D = (E)	minutes
	37	Typical output per day (F)	items
	38	Ideal cycle time (G)	minu./item
	39	Actual cycle time (H)	min/item
	40	Actual processing time = F*H	minutes
	41	Availability = (E/(A-B))*100	%
	42	Operating speed rate = G/H*100	%
	43	Net operating rate = (F*H)/E*100	%
	44	Performance efficiency = Operating speed rate *Net operating rate /100	%
	45	Overall Equipment Effectiveness	%

P.I.	Mach01	Mach02	Mach03	Mach04	Mach05	Mach06	Sub total
Item No.							
1	4	3	6	4	4	5	
2	1.5	2	1.5	2	1.5	1.5	
3	5.5	5	7.5	6	5.5	6.5	
4	6627.43	10366.48	4924.33	9949.77	22034.0671	23464.02	
5	946.8	1480.9	1145.2	1530.7	2644.1	2607.1	
6	8	8	7	7	8	7.5	
7	4	4	4	4	4	4	
8	17.5	17	18.5	17	17.5	18	
9	10	9	10	8	3	3	
10	70	63	43	52	25	27	
11	0.0011	0.0007	0.0009	0.0007	0.0004	0.0004	
12	66274.27	93298.36	49243.32	79598.15	66102.20	70392.05	424908.35
13	946.78	1480.93	1145.19	1530.73	2644.09	2607.11	
14	0.58	0.34	0.65	0.39	0.21	0.25	
15	9.17	7.50	7.68	7.43	5.73	9.75	
16	5.5	5	7.5	6	5.5	6.5	
17	0.581	0.338	0.655	0.392	0.208	0.249	
18	110	110	110	110	110	110	
19	38500	31500	32250	31200	13750	17550	164750
20	60	55	60	40	30	30	
21	385	315	322.5	312	137.5	175.5	1647.5
22	1225	1071	795.5	884	437.5	486	4899
23	96.5	97	95.5	95.5	96	95	
24	263059	257670	139239	271124.5	208224	141930	
25	272600	265639	145800	283900	216900	149400	
26	99.42	99.66	99.35	99.61	99.79	99.75	
27	97.36	98.11	97.28	98.30	99.21	99.00	
28	43698.92	61233.61	29251.42	51962.54	52145.09	47219.18	
29	65.94	65.63	59.40	65.28	78.89	67.08	
30	480	480	480	480	960	960	
31	20	20	20	20	40	40	
32	460	460	460	460	920	920	
33	25	25	32	32	65	65	
34	18	22	27	33	40	43	
35	63	67	79	85	145	148	
36	417	413	401	395	815	812	
37	400	450	350	380	750	900	
38	0.5	0.6	0.7	0.6	0.8	0.8	
39	0.8	0.85	0.9	0.9	0.9	0.9	
40	320	382.5	315	342	675	810	
41	90.65	89.78	87.17	85.87	88.59	88.26	
42	62.5	70.59	77.78	66.67	88.89	88.89	
43	76.74	92.62	78.55	86.58	82.82	99.75	
44	47.96	65.38	61.10	57.72	73.62	88.67	
45	41.96	56.93	50.86	47.33	62.61	74.35	

Example Worksheet 17 Section 17: Facilities and Machine (Group) Performance Profiling (Current)

Competitive Criteria	Performance Measure	Performance Indicators	Unit	Mach01
			Weight of Importance of each Machine	10.72
Quality	Not Right First Time	Quality Rate	%	96.5
Delivery LeadTime	Delivery Schedule Achievement	Facilities Performance Efficiency	%	47.96
Delivery Reliability	Equipment Utilisation	Overall Equipment Effectiveness	%	41.96
Delivery Flexibility	Equipment Utilisation	Equipment Availability	%	90.65
Volume Flexibility	Equipment Utilisation	Overall Equipment Effectiveness	%	41.96
Cost	Maintainability	Total Maintenance Cost / Total Life Cycle Cost	%	60



Note:
1. Quality Rate = quality products / total products produced
2. Overall Equipment Effectiveness = overall availability * process rate* quality rate
3. Equipment Availability = (Schedule time - all unplanned time) / scheduled time

Example Worksheet 17

Section 17: Facilities and Machine (Group) Performance Profiling (Current)

Performance Indicators	Unit	Mach02	Mach03	Mach04	Mach05	Mach06	Overall Performance
	Weight of Importance of each Machine	12.06	17.84	17.84	20.1	21.44	
Quality Rate	%	97	95.5	95.5	96	95	95.78
Facilities Performance Efficiency	%	65.38	61.10	57.72	73.62	88.67	68.03
Overall Equipment Effectiveness	%	56.93	50.86	47.33	62.61	74.35	57.41
Equipment Availability	%	89.78	87.17	85.87	88.59	88.26	88.15
Overall Equipment Effectiveness	%	56.93	50.86	47.33	62.61	74.35	57.41
Total Maintenance Cost / Total Life Cycle Cost		55	60	40	30	30	43.37

Example Worksheet 18 (Section 18: Current Facilities and Machine (Group) SWOT Analysis

Strengths: Those activities, systems, technologies, procedures and so on which the company does uniquely well.

Category	Feature	Reason
Management and Organisation	Management Systems	Good control, computerised facilities, management aims to operate strategically, implementing business process re-engineering
	Employee	Employee with experience, mean age of 30, people with good communication and train equipment on job training
Operations	Quality	Adopted ISO 9000, people with qualified license, new equipment will promote quality
	Design Flexibility	Have competent technical engineers
	Dependability	Company operates reliably
	Technology	Company possesses better technology than national competitors
	Equipment Age	Company possesses relatively new machines
Finance	Capital Structure	Some machines have already depreciated
	Accounting System	Organised and computerised system
Others	Image of company	Company has a good reputation for quality

Weaknesses: Those items (as strengths) which the company does not perform to an acceptable standard.

Category	Feature	Reason
Management and Organisation	Personnel policies	Old system still in operation
Operation	Delivery Lead Time	Long lead-time products, mainly due to raw materials, long set-up and change over times
	Capacity	To increase capacity will need to re lay out the production line and space, bottle neck equipment needs to be identified
	Volume Flexibility	Majority of the existing facilities have been given fixed productivity rate with low expansion ability
	Location	Factory is far from export outlets
	Material availability	Factory finds it hard to get raw materials
	Performance	Equipment performance measurement system development is required, equipment performance monitoring project is also required
	Maintenance	Total productive maintenance plan is required

Opportunities: Those activities, events or potential events where the company might additionally exploit their competitiveness in the market.

Category	Feature	Reason
Economic	Interest rates	Hold substantial inventory, raw material and equipment spares
Social and Political	Government legislation	Customer procedures slow company operation arrangement, purchasing legislation limitation
Market and Competition	Supplier dependence	Limited supplier for spares especially for old equipment
Products and Technology	Fabrication technique	General purpose equipment will easily face simulation of the products by the competitor
Others	Raw material	Limited resources of raw materials

Threats: Those activities, (systems etc.) or events or potential events which might prevent the company reaching the corporate strategic objectives.

Category	Feature	Reason
Economic	Availability of credit	Government assistance, low interest loans
	Level of employment	Easily recruit and retain workforce
Market and Competition	Customer plans	Customers are planning to expand
	Competitor plans	Some competitors are planning to leave the market
Products and Technology	New technology	New design of products will open new market attraction
	Old technology	Maintain old but low maintenance cost equipment to increase the design support flexibility and also take care of portion of the old product service requirement

Note:
Before the SWOT analysis, a check list can be generated for the audit process. A typical check list example is shown in the following table.

Example Corporate Business SWOT Analysis Check List

Item	Influence Factors	SWOT Analysis				Description
		Internal Analysis		External Analysis		
		Strengths	Weaknesses	Opportunities	Threats	
Competitive Situation- What the others are doing	Number of competitors			√		• Less than ten in U.K.
	Kind of competitors			√		• CNC machining, Prototyping, Value engineering none of the competitors is capable of operating all of the activities

Item	Influence Factors	SWOT Analysis				Description
		Internal Analysis		External Analysis		
		Strength	Weakness	Opportunity	Threat	
Competitive Situation- What the others are doing	Number of competitors			√		• Less than ten in U.K.
	Kind of competitors			√		• CNC machining, prototyping, Value engineering. • None of the competitors is capable of operating all of the activities
	Resources of competitors				√	• CNC machining, Prototyping, Value engineering
Economics - Understanding economic constraints and opportunities common to the industry	Volume change	√				• Working six days a week on a day-shift basis • A night shift on three machines
Technology - Understanding constraints and opportunities to the technology	Product change	√				• Flexible manufacturing systems
	Process			√		• Make-to-order business • Short throughput time
	Equipment			√		Two sites - Kent site and PML site
					√	• Full work load, small batches, long set-up times, saturation of production capacity
	Critical determinants				√	• Need to expand production capacity
	Materials	√				• Keep low stock due to a make-to-order policy
	Trends			√		• Three main customers (90% of the products, another 10% with smaller batch requirements) • Telecommunications – 40% • Power Distribution – 25% • Aerospace – 25%
	Objectives			√		• Two milling centres in PML site with under utilisation at 10 hours per day • Increase market share of plastic parts and composite part machining to increase profit

Note:

1. This example contains general information about an example manufacturing company for the demonstration of the implementation of SWOT Analysis.
2. The strength of this company is that the company has advantage of high-technology, latest manufacturing equipment, quality level, and niche products category. This result also means that the example company can satisfy the customer requirements of quality and flexibility. The price/cost might be reduced which depends on the volume of the contract order and the management of the existing facilities and relative operational implementation.
3. The threat and weakness is that the capacity is always full loaded except for maintenance and repair works. This might be a disadvantage to receiving more contracts in the future, unless the company can expand more capacity. If the capacity could not be expanded, the threat is to lose delivery reliability on due date. The

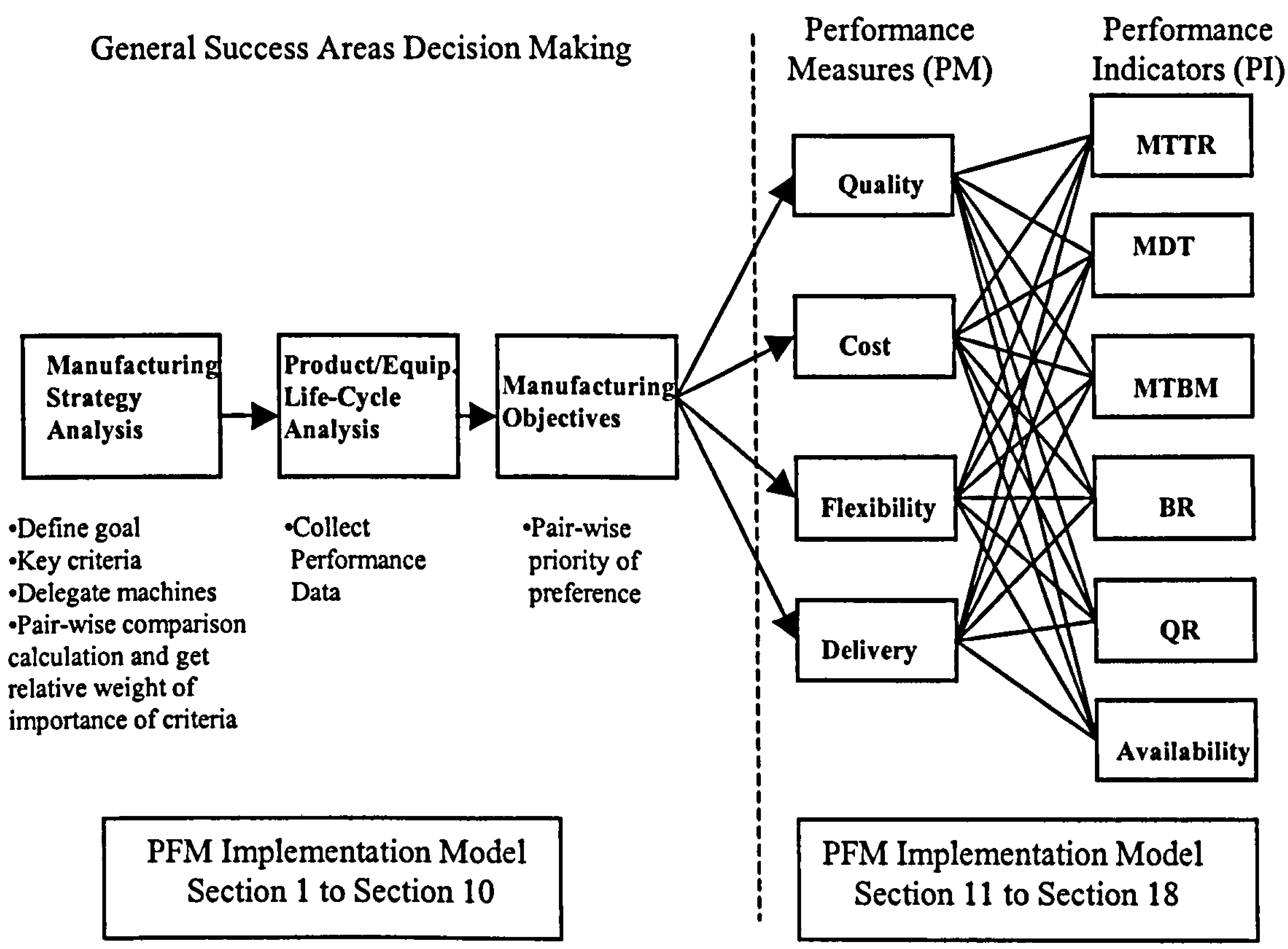
customer might go to another company with a similar facility and would not come back.

4. The example company should use the strengths to create more opportunities in the market whilst placing more focus on the weaknesses in order to improve.

Example Section 19: Facilities and Machine (Group) Improvement Decision-Making Assessment

This example describes the implementation process, especially the process to establish the structure of a PFM performance monitoring system. The test process is implemented with the application of AHP (Analytic Hierarchy Process) methodology application. The example provides an outline of the whole process which is shown in following steps:

1. ***Stepl: Define the goal, key criteria (PM/PI) and compare the relative "PREFERENCE" with respect to the goal.*** The key point is that the relative "PREFERENCE' of each criterion is decided based on the corporate strategic objectives and business focus (general success areas). Step 1 is accomplished with the establishment of a hierarchical structure of the performance measurement system as shown in following Figure. The test result is as shown in example step one.



Example Hierarchical Structure of Performance Measurement System for Decision-Making Assessment of Replacing Existing Facilities

2. ***Step 2: Define the delegate machines involved in decision making assessment.*** The test result is as shown in example step two.
3. ***Step 3: Derived priorities of each criterion with respect to goal.*** The test result is as shown in example step three.

4. ***Step 4: Pair-wise comparison of each delegate machine with respect to each criterion*** The test result is as shown in example step four.
5. ***Step 5: Collecting historic operational data of each machine and pair-wise comparison calculation to get the relative weight of each machine with respect to each criterion (PI).*** The test result is as shown in example step five and example step six.
6. ***Step 6: Total pair-wise comparison of each delegate machine with respect to each criterion*** - The larger the total value means the higher the possibility that the machine will be replaced. The test result is as shown in example step seven.

Example Step 1 of Section 19

Step 1: Define the goal, key criteria (PM/PI) and compare the relative "PREFERENCE" with respect to the Goal.

Goal: Replacing existing facility

Key point - The relative preference of each criterion is decided based on the corporate strategic objective and business focus

replacement policy for existing machines

Node: 0

Compare the relative PREFERENCE with respect to: GOAL

	AV	QR	BR	MTTR	MTBM	MTBR
MDT	(2.0)	(1.5)	2.0	1.0	1.0	1.0
AV		1.4	4.0	2.0	2.0	2.0
QR			3.0	1.5	1.5	1.5
BR				(2.0)	1.0	(2.0)
MTTR					1.0	1.0
MTBM						1.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	replacement policy for existing machines
MDT	Mean Maintenance Downtime
AV	Operational Availability
QR	Quality Rate
BR	Breakdown Frequency
MTTR	Mean Time To Repair
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement

Example Step 2 of Section 19

Step 2: Define the delegate machines involved in replacing decision making assessment

Goal: Replacing existing facility

Key point - The delegate machines are those production facilities used to manufacturing the products.

replacement policy for existing machines

GOAL

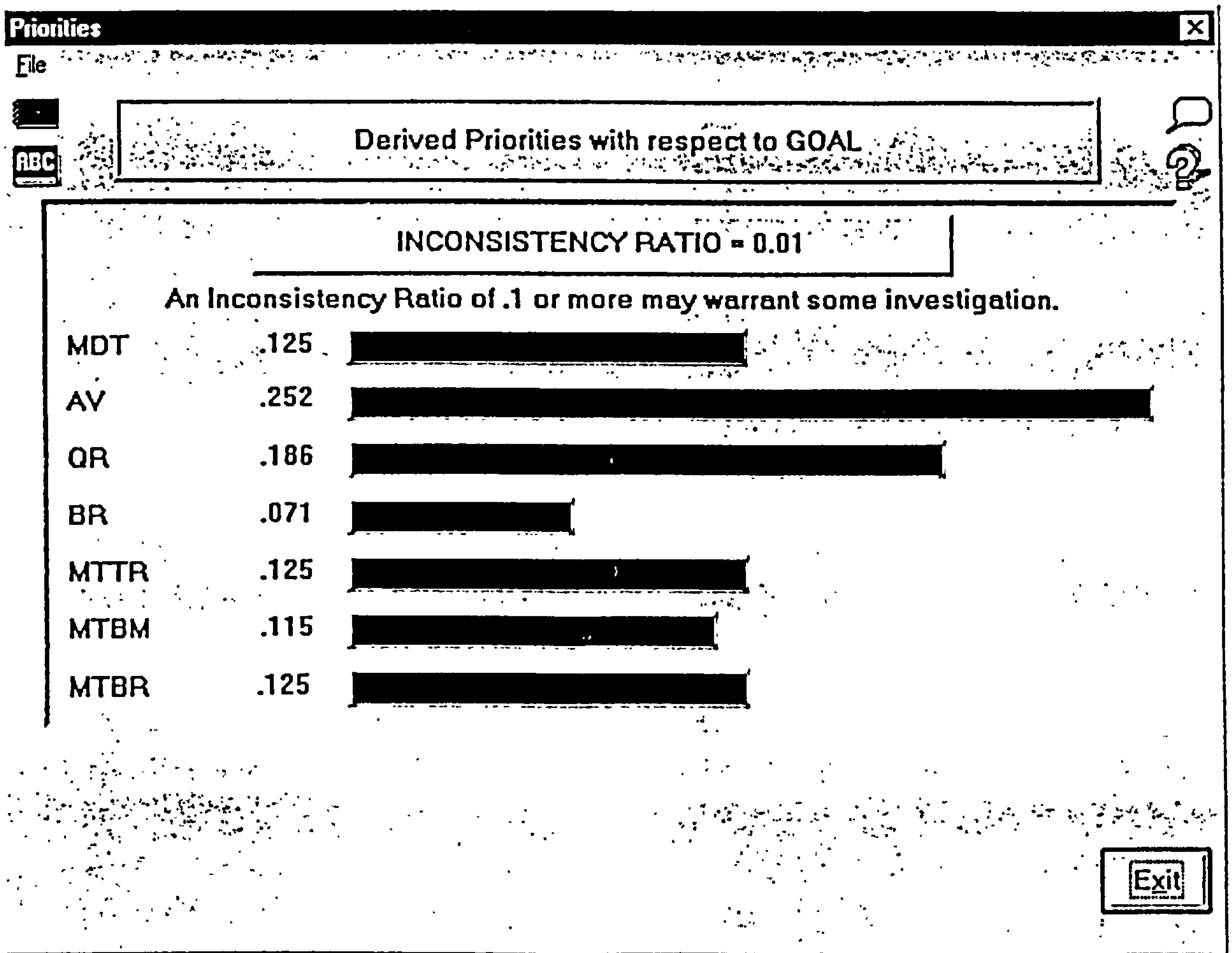
MDT	AV	QR	BR	MTTR	MTBN
MACHINE0	MACHIN01	MACHIN01	MACHIN01	MACHIN01	MACHIN0
MACHINO2	MACHIN02	MACHIN02	MACHIN02	MACHIN02	MACHIN0
MACHIN03	MACHIN03	MACHIN03	MACHIN03	MACHIN03	MACHIN0
MACHIN04	MACHIN04	MACHIN04	MACHIN04	MACHIN04	MACHIN0
MACHIN05	MACHIN05	MACHIN05	MACHIN05	MACHIN05	MACHIN0
MACHIN06	MACHIN06	MACHIN06	MACHIN06	MACHIN06	MACHIN0
MACHIN07	MACHIN07	MACHIN07	MACHIN07	MACHIN07	MACHIN0
MACHIN08	MACHIN08	MACHIN08	MACHIN08	MACHIN08	MACHIN0
MACHIN09	MACHIN09	MACHIN09	MACHIN09	MACHIN09	MACHIN0

Abbreviation	Definition
AV	Operational Availability
BR	Breakdown Frequency
MACHIN01	Machine01
MACHIN02	Machine02
MACHIN03	Machine03
MACHIN04	Machine04
MACHIN05	Machine05
MACHIN06	Machine06
MACHIN07	Machine07
MACHIN08	Machine08
MACHIN09	Machine09
MACHINE0	Machine01
MACHINO2	Machine02
MDT	Mean Maintenance Downtime
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement
MTTR	Mean Time To Repair
QR	Quality Rate

Example Step 3 of Section 19

Step 3: Derived priorities of each criterion (PI) with respect to Goal

Goal: Replacing existing facility



Example Step 4 of Section 19

Step 4: Collecting historic performance data of each machine and pair-wise comparison calculation to get the relative weight of each machine with respect to each criterion

Equipment Performance Assessment Table

Competitive criteria	Performance Measure	Unit	Machine01	Machine02	Machine03	Machine04	Machine05	Machine06
Maintainability	Mean Time Between Replacement (MTBR)	hours	500	450	450	500	600	600
	Mean Time Between Maintenance (MTBM)	hours	80	85	90	85	60	70
	Mean Time To Repair (MTTR)	hours	4	4	6	5	5	3
	Mean Maintenance Downtime (MDT)	hours	30	20	20	17	16	12.00
Availability	Operational Availability(Av)	%	72.73	80.95	81.82	83.33	78.95	85.37
Quality	Quality Rate	%	96	99	95	96	94	97
Supportability	Breakdown frequency	No. off order	9	3	16	12	8	4

Example Step 5 of Section 19

Step 5: Pair-wise comparison of each delegate machine with respect to each criterion

Example 5 shows the relative "PREFERENCE" with respect to goal in the assessment of criterion "MDT".

replacement policy for existing machines

Node: 10000

Compare the relative PREFERENCE with respect to: MDT < GOAL

	MACHINO2	MACHIN03	MACHIN04	MACHIN05	MACHIN06	MACHIN07	MACHIN08	MACHIN09
MACHINE0	1.5	1.5	1.8	1.9	2.5	4.3	5.0	5.0
MACHINO2		1.0	1.2	1.3	1.7	2.9	3.3	3.3
MACHIN03			1.2	1.3	1.7	2.9	3.3	3.3
MACHIN04				1.1	1.4	2.4	2.8	2.8
MACHIN05					1.3	2.3	2.7	2.7
MACHIN06						1.7	2.0	2.0
MACHIN07							1.2	1.2
MACHIN08								1.0

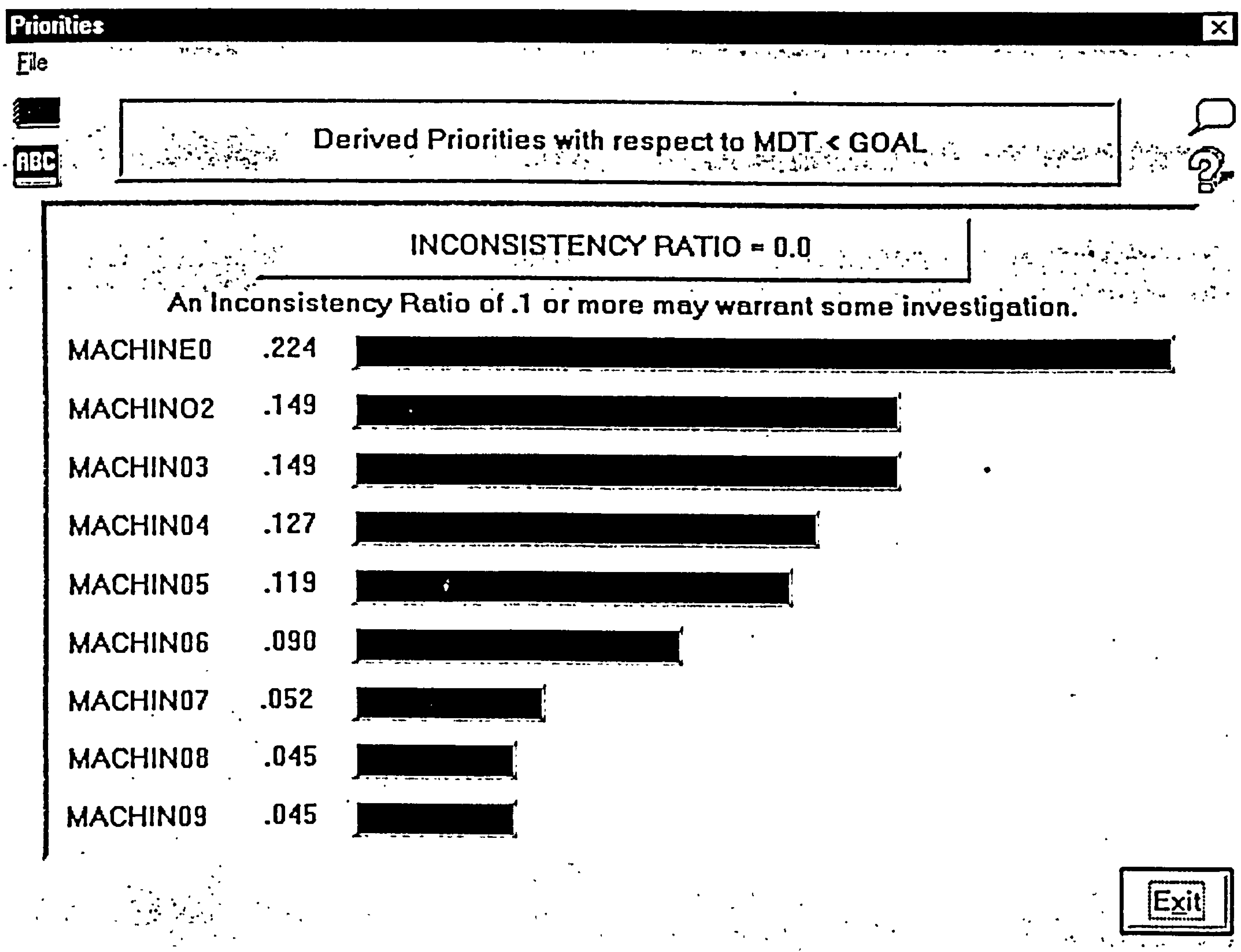
Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	replacement policy for existing machines
MDT	Mean Maintenance Downtime
MACHINE0	Machine01
MACHINO2	Machine02
MACHIN03	Machine03
MACHIN04	Macnine04
MACHIN05	Machine05
MACHIN06	Machine06
MACHIN07	Machine07
MACHIN08	Machine08
MACHIN09	Machine09

Example Step 6 of Section 19

Step 5: Pair-wise comparison of each delegate machine with respect to each criterion

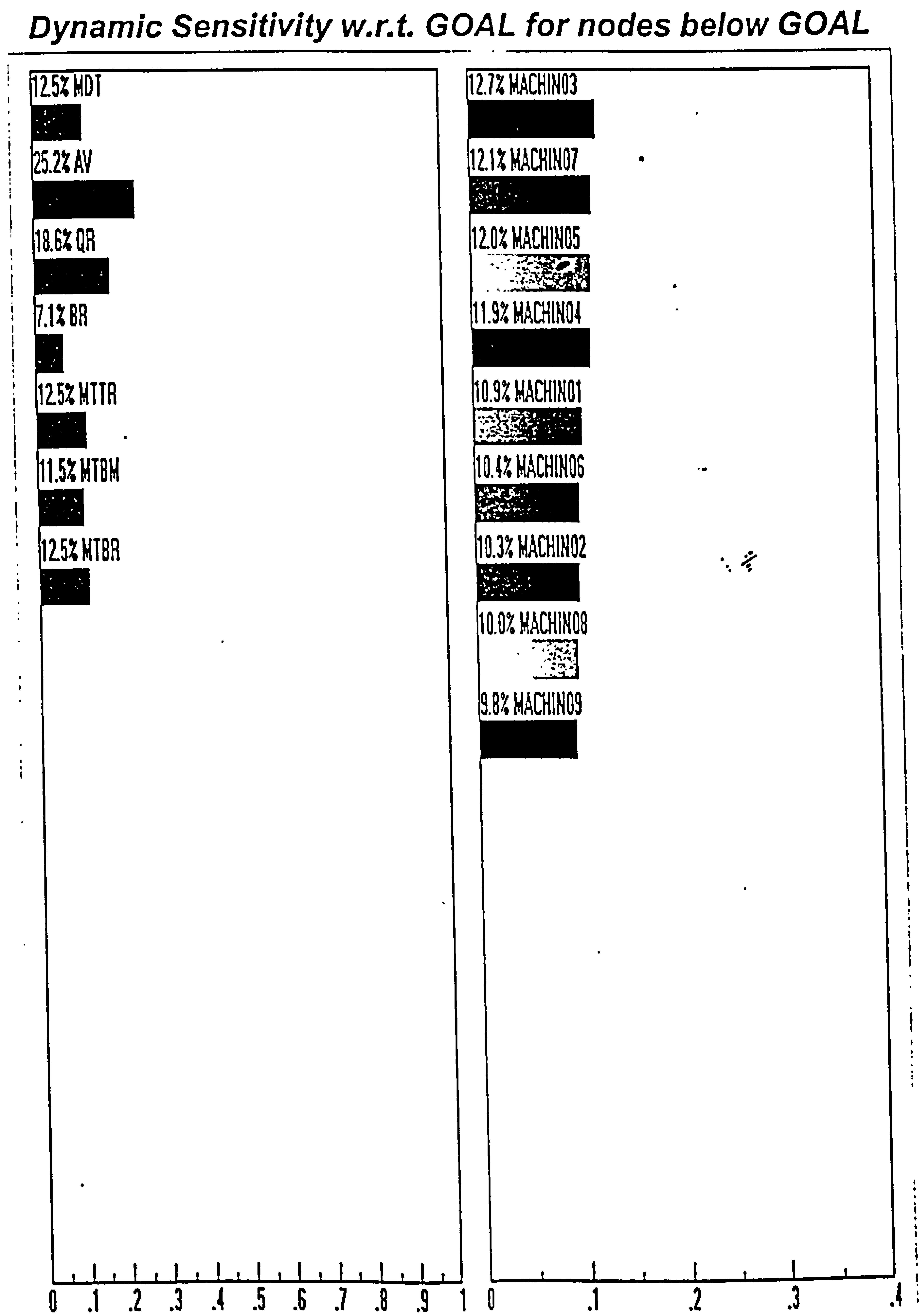
Example 6 shows the pair-wise results of the delegate machines with respect to the goal in the assessment of criterion "MDT"



Example Step 7 of Section 19

Step 6: Total pair-wise comparison of each delegate machine with respect to each criterion

Key point - The larger the total value means the higher the possibility that the machine will be replaced



Example *Section 20: Equipment Performance Monitoring Project*

Worksheet 20

Competitive Criteria	Performance measure	Performance Indicator	Objectives	Current	Time Span	Assessment Period	Responsible Personnel or Work Centre
Quality	Not Right First Time	Quality Rate	increase 3% = 98.5%	96.62%	3 years	3 months	Quality Assurance
Delivery Lead Time	Delivery Schedule Achievement	Equipment Performance Efficiency	Increase 28% = 95%	67%	3 years	3 months	Production Planning & Control Dept.
Delivery Reliability	Equipment Utilisation	Overall Equipment Effectiveness	Increase 27% = 85%	58%	3 years	3 months	Maintenance dept.
Design Flexibility	Equipment Utilisation	Equipment Availability	Increase 1% = 90%	89%	3 years	3 months	Fabrication Division
Volume Flexibility	Equipment Utilisation	Overall Equipment Effectiveness	Increase27% = 85%	58%	3 years	3 months	Maintenance dept.
Cost / Price	Maintainability	Total Maintenance Cost / Toal Sales	Decrease 2% =8%	10%	3 years	3 months	Maintenance dept.

Note:

1. The decision-making of the choice of P.M. and P.I. to represent an integrated assessment for each competitive criterion should refer to the Competitive Criteria, P.M. and P.I. Matrix table.
2. In this example case, the strategic requirement of quality is transformed into the assessment of the performance on "Not Right First Time" and "Quality Rate" of the machine (group).
3. The other transformation follows the same rule.

Financial Perspective	How do we look to shareholder?		Competitive Criteria				
Goals	Measures	Q	DLT	DR	DF	VF	C/P
Cost	Toatl Life Cycle Cost / Total Sales						X
Volume Flexibility	Overall Equipment Effectiveness					X	
Cost	Net Present Value						X
Cost	Stock turns						X

Customer Perspective	How do customers see us?		Competitive Criteria				
Goals	Measures	Q	DLT	DR	DF	VF	C/P
Delivery Lead Time	Overall Equipment Effectiveness	X	X	X	X	X	
Quality	Not right first time	X					X
Delivery Reliability	Promised date compliance			X			

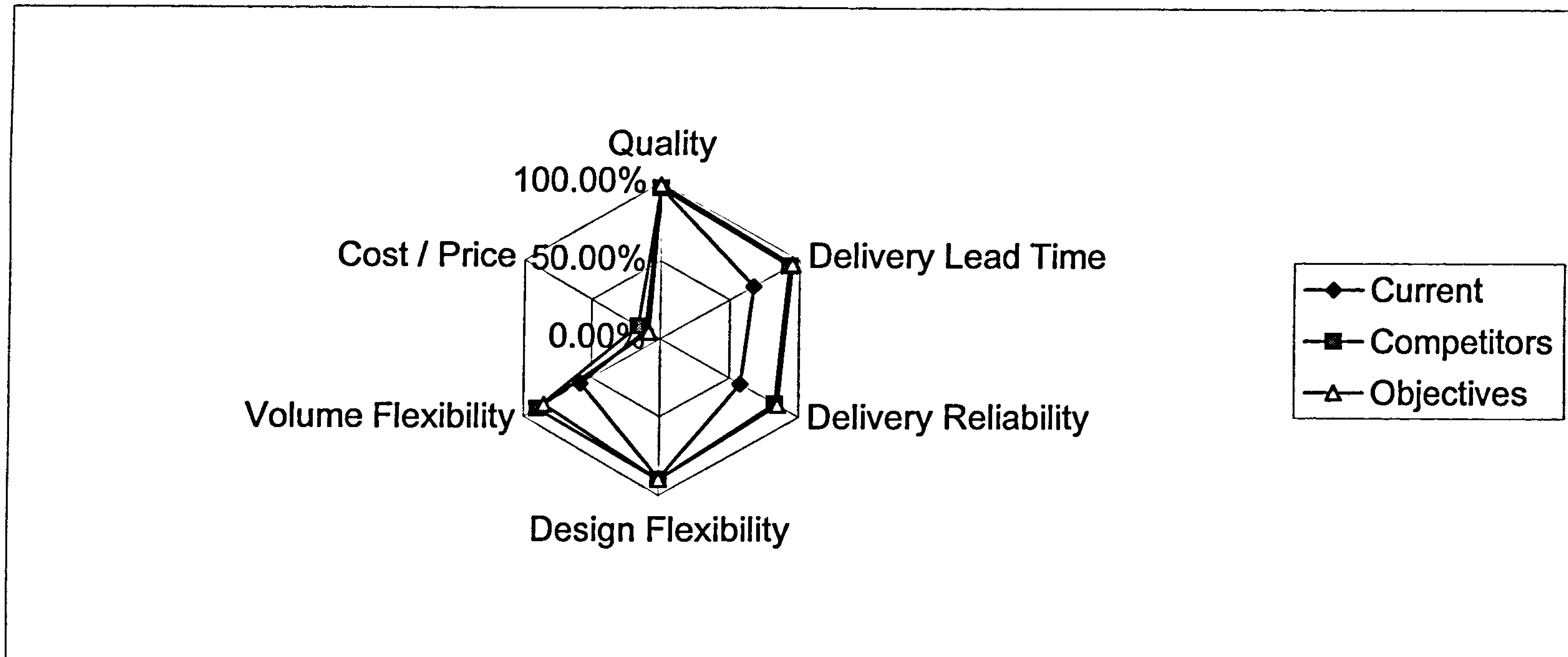
Internal Business Perspective	What must we excel at?		Competitive Criteria				
Goals	Measures	Q	DLT	DR	DF	VF	C/P
Productivity	Equipment Productivity			X		X	X
Capacity	Utilisation & Efficiency		X	X		X	
Quality	Quality Rate	X					X

Innovation and Learning Perspective	Can we continue improvement and increase value		Competitive Criteria				
Goals	Measures?	Q	DLT	DR	DF	VF	C/P
Supportability	Overall Equipment Effectiveness	X	X	X	X	X	
Maintainability	Mean Time Between Maintenance			X			X
Reliability	Mean Time Between Failure	X		X	X		

Example Worksheet 22

Section 22: Current Facilities and Machine (Groups) Performance versus Competitors Performance Benchmark

Performance measure	Performance Indicator	Competitive criteria	Performance Requirements		
			Current	Competitors	Objectives
Not Right First Time	Quality Rate	Quality	96.62%	96.50%	99%
Delivery Schedule Achievement	Equipment Performance Efficiency	Delivery Lead Time	67%	93%	95%
Equipment Utilisation	Overall Equipment Effectiveness	Delivery Reliability	58%	83%	85%
Equipment Utilisation	Equipment Availability	Design Flexibility	89%	90%	90%
Equipment Utilisation	Equipment Availability	Volume Flexibility	58%	90%	85%
Maintainability	Total Maintenance Cost / Toal Sales	Cost / Price	10%	16%	8%



Note:
1. The P.M. and P.I. Chosen here are examples, the company should make their own choices through an organised reviewing board.

Example *Section 23: Facilities and Machine (Group) Performance Report (1st stage improvement*

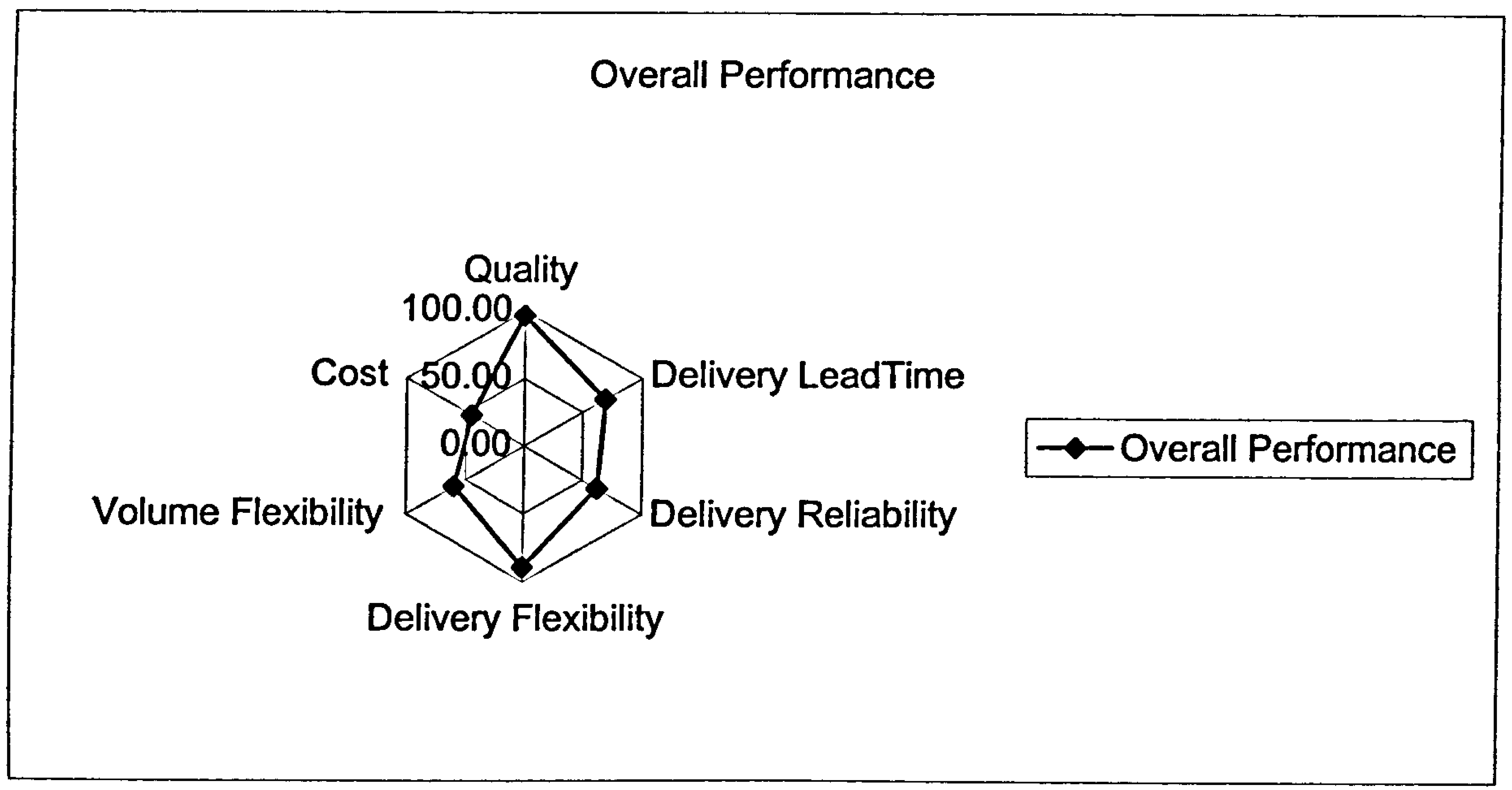
Performance Measures (P.M.)	P.I. Item No.	Performance Indicators (P.I.)	Unit
Maintainability	1	MTTR (Mean Time To Repair)or (Mean Corrective Time)	hours
	2	Mean preventative maintenance time	hours
	3	Mean Active Maintenance Time	hours
	4	MTBR (Mean Time Between Replacement)	hours
	5	MTBM (Mean Time Between Maintenance)	hours
	6	MLDT (Mean Logistics Delay Time)	hours
	7	MADT (Mean Administrative Delay Time)	hours
	8	MMDT (Mean Maintenance Downtime, include MLDT and MADT))	hours
	9	RF (Replacement Frequency)	times
Reliability	10	BR (Breakdown Frequency) or Number of failures	times
	11	Failure rate (Number of failures / total operating hours)	times/hr
	12	Total operating hours	hours
	13	MTBF (Mean Time Between failure)	hours
Maintenance	14	MMH/OH (Maintenance man hours per System operating hr)	%
Labour	15	MMH/month (Maintenance man hours per month)	hrs/mon
	16	MMH/MA (Maintenance man hours per Maintenance action)	hours
Cost	17	Maintenance cost per system operating hour	£/hr
	18	Cost per maintenance action	£
	19	Total maintenance cost	£
	20	Total maintenance cost / Total life cycle cost	%
	21	Total maintenance man hours (Exclude MLDT and MADT)	hours
	22	Total maintenance man hours (Include MLDT and MADT)	hours
Quality	23	Quality rate (Quality products / Total products produced)	%
	24	Quality product	pieces
	25	Total products produced	pieces
	26	Availability (Schedule time - All unplanned time) / Schedule time	%
	27	Process rate (Ideal cycle time / Actual cycle time) = Efficiency ratio	%
	28	Total Cycle Time =Total working hours + Total maintenance	hours
		man hours (Include MLDT and MADT)	
Flexibility	29	Capacity ratio (Actual hours worked / Budgeted standard hours)* 100%	%
	30	Working hours per day (A)	minutes
	31	Planned downtime per day (scheduled maintenance, meetings, etc) (B)	minutes
	32	Loading time per day = A - B	minutes
	33	Typical setup time per day (C)	minutes
	34	Typical adjustment time (D)	minutes
	35	Stoppage per day	minutes
	36	Operating time per day = A-B-C-D = (E)	minutes
	37	Typical output per day (F)	items
	38	Ideal cycle time (G)	min/item
	39	Actual cycle time (H)	minu/item
	40	Actual processing time = F*H	minutes
	41	Availability = (E/(A-B))*100	%
	42	Operating speed rate = G/H*100	%
	43	Net operating rate = (F*H)/E*100	%
	44	Performance efficiency = Operating speed rate *Net operating rate /100	%
	45	Overall Equipment Effectiveness	%

Example Section 23: Facilities and Machine (Group) Performance Report (1st stage improvement)

P.I.	Mach01	Mach02	Mach03	Mach04	Mach05	Mach06	Sub total
Item No.							
1	3.75	3.5	6	3.9	4	4.75	
2	2	2.5	1.5	2.5	2	1.75	
3	5.75	6	7.5	6.4	6	6.5	
4	2836.26	5006.55	2032.57	5107.85	7390.36973	7791.11	
5	354.5	715.2	444.6	681.0	1567.7	1335.6	
6	7	7	7	7	7	7	
7	3.5	3.5	3.5	3.5	3.5	3.5	
8	16.25	16.5	18	16.9	16.5	17	
9	15	12	14	10	7	6	
10	120	84	64	75	33	35	
11	0.0028	0.0014	0.0022	0.0015	0.0006	0.0007	
12	42543.92	60078.61	28455.92	51078.54	51732.59	46746.68	280636.27
13	354.53	715.22	444.62	681.05	1567.65	1335.62	
14	1.62	0.84	1.69	0.94	0.38	0.49	
15	16.43	12.00	11.43	11.43	8.25	12.64	
16	5.75	6	7.5	6.4	6	6.5	
17	1.622	0.839	1.687	0.940	0.383	0.487	
18	110	110	110	110	110	110	
19	69000	50400	48000	48000	19800	22750	257950
20	55%	45%	48%	45%	42%	40%	
21	690	504	480	480	198	227.5	2579.5
22	1950	1386	1152	1267.5	544.5	595	6895
23	97	97.5	96	96	97	97	
24	347018	322690	159840	354288	276304.5	207435	
25	357750	330965	166500	369050	284850	213850	
26	98.38	99.16	98.31	99.06	99.62	99.51	
27	97.36	98.11	97.28	98.30	99.21	99.00	
28	43698.92	61233.61	29251.42	51962.54	52145.09	47219.18	
29	41.33	41.86	37.62	41.02	48.61	46.11	
30	480	480	480	480	960	960	
31	20	20	20	20	35	35	
32	460	460	460	460	925	925	
33	20	20	30	30	60	60	
34	15	20	25	30	35	40	
35	55	60	75	80	130	135	
36	425	420	405	400	830	825	
37	420	475	375	390	800	880	
38	0.5	0.6	0.7	0.6	0.8	0.8	
39	0.75	0.8	0.85	0.85	0.9	0.85	
40	315	380	318.75	331.5	720	748	
41	92.39	91.30	88.04	86.96	89.73	89.19	
42	66.67	75.00	82.35	70.59	88.89	94.12	
43	74.12	90.48	78.70	82.875	86.75	90.67	
44	49.41	67.86	64.81	58.5	77.11	85.33	
45	44.28	60.41	54.78	48.83	67.11	73.82	

Example Worksheet 24 Section 24: Facilities and Machine (Group) Performance Profiling (1st stage improvement)

Competitive Criteria	Performance Measure	Performance Indicators	Unit	Mach01
			Weight of Importance of each Machine	10.72
Quality	Not Right First Time	Quality Rate	%	97
Delivery Lead Time	Delivery Schedule Achievement	Facilities Performance Efficiency	%	49.41
Delivery Reliability	Equipment Utilisation	Overall Equipment Effectiveness	%	44.28
Delivery Flexibility	Equipment Utilisation	Equipment Availability	%	92.39
Volume Flexibility	Equipment Utilisation	Overall Equipment Effectiveness	%	44.28
Cost	Maintainability	Total Maintenance Cost / Total Life Cycle Cost	%	55



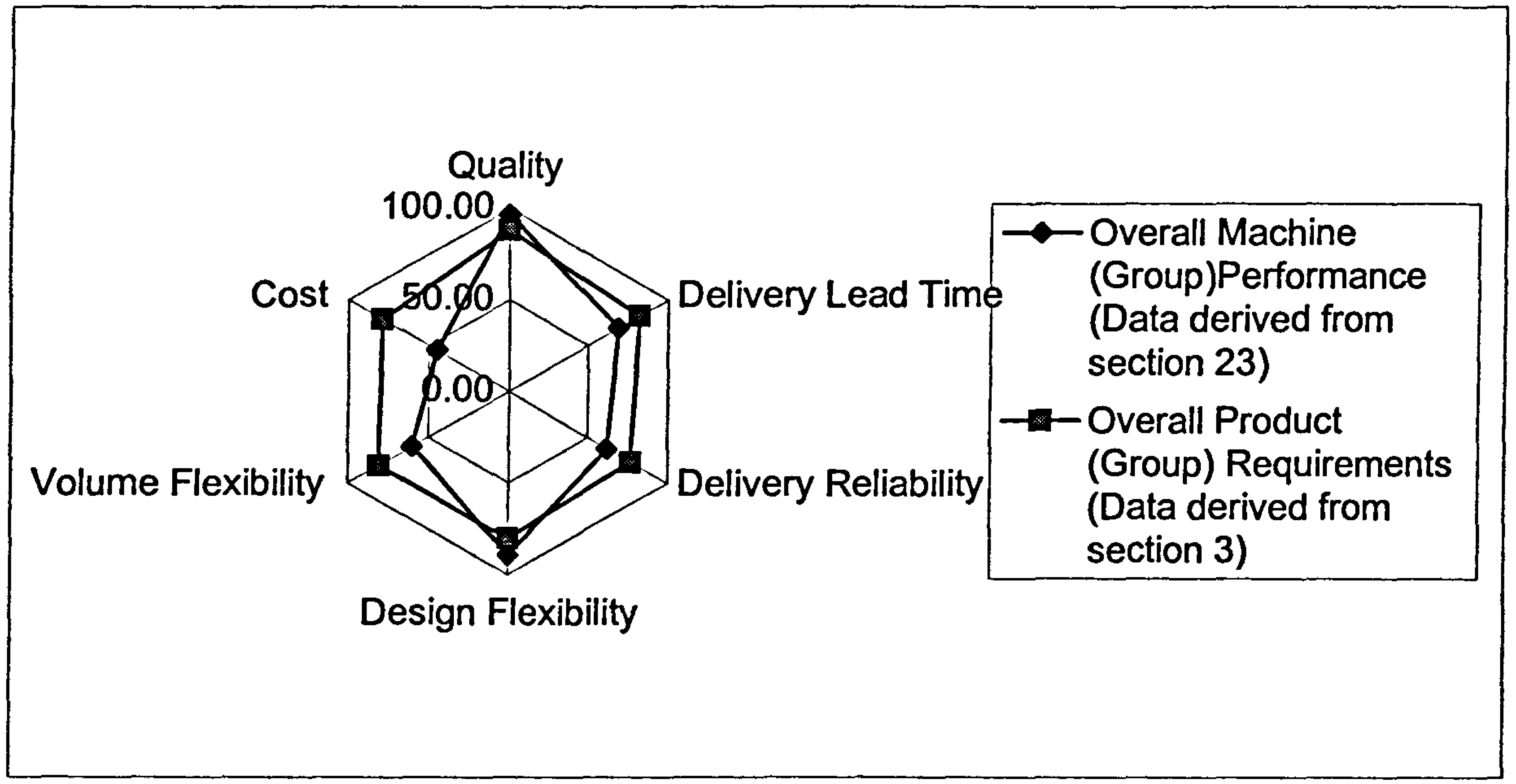
Note:
1. Quality Rate = quality products / total products produced
2. Overall Equipment Effectiveness = overall availability * process rate* quality rate
3. Equipment Availability = (Schedule time - all unplanned time) / scheduled time

Example Worksheet 24 *Section 24: Facilities and Machine (Group) Performance Profiling (1st stage improvement)*

Performance Indicators	Unit	Mach02	Mach03	Mach04	Mach05	Mach06	Overall Performance
	Weight of Importance of each Machine	12.06	17.84	17.84	20.1	21.44	
Quality Rate	%	97.5	96	96	97	97	96.70
Facilities Performance Efficiency	%	67.86	64.81	58.50	77.11	85.33	69.27
Overall Equipment Effectiveness	%	60.41	54.78	48.83	67.11	85.33	62.30
Equipment Availability	%	91.30	88.04	86.96	89.73	89.19	89.29
Overall Equipment Effectiveness	%	60.41	54.78	48.83	67.11	73.82	59.84
Total Maintenance Cost / Total Life Cycle Cost		45	48	45	42	40	44.93

Example Worksheet 25 Section 25: Product (Group) Requirement versus Facilities and Machine (Group) Performance Gap Analysis

Competitive Criteria	Overall Machine (Group)Performance	Overall Product (Group) Requirements
	(Data derived from section 23)	(Data derived from section 3)
Quality	96.70	88.17
Delivery Lead Time	69.27	82.60
Delivery Reliability	62.30	77.02
Design Flexibility	89.29	80.42
Volume Flexibility	59.84	80.85
Cost	44.93	78.62



Analysis:

1. From the gap analysis, the overall performance of the facilities and machine (group) with respect to the competitive criteria of design flexibility and quality can satisfy the customers requirements.
2. The performance of the facilities with respect to the competitive criteria of cost, volume flexibility, and delivery reliability still need more improvements.

Example Worksheet 26

Production Facilities Management Decision-Making Assessment

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Capacity	Total capacity	Market and demand structure	20	60	100
		Floor space	20	100	100
		Plant/equipment size	20	60	100
		Equipment availability	20	60	100
		Availability of manpower	60	60	60
		Availability of cash	20	100	100
	Variation Satisfaction	Degree of flexibility	20	60	100
	Expand Methods	How	0	60	100
		Size of increment	0	60	100
	Contraction method	How	0	60	100
		Size of contraction	0	60	100
	Timing	When to expand or contract	0	60	100
	Bottleneck	Productivity	60	60	100
	Demand Forecasting	Required quantity	60	60	100
		How monitor	100	60	60
		How forecast	100	60	60
Facilities	Number	Number of equipment	60	60	100
	Specification	Size	60	100	100
		Capability	100	100	100
		Utilities	20	60	100
	Location	Proximity to market	20	60	100
		Integration with the organisation	20	60	100
		Availability of labour and skills	60	60	100
		Availability of amenities	20	60	100
		Availability of transport	60	60	100
		Availability of input	20	60	100
		Availability of services	20	60	100
		Suitability of land and climate	20	60	100
		Regional regulation	20	20	60
		Room for expansion	20	60	60
		Safety requirement	60	60	60
		Political, cultural and economic situation	20	20	60
		Special grants, regional taxes and import / export barriers	20	20	60
		Plant layout	60	60	100
		Fuel or energy, availability and cost	60	60	100
	Lay-out	Maximum flexibility	20	60	100
		Maximum co-ordination	20	60	100
	Function Integration	Enterprise	60	60	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Facilities		Maximum visibility	20	60	100
		Minimum distance	60	100	100
		Minimum handling	60	100	100
		Inherent safety	20	60	60
		Efficient process flow	20	60	100
		Identification	20	60	60
	Focus / Specialisation	Type	20	60	100
	Function Integration	Enterprise	60	60	100
		Manufacturing	100	100	100
		Support Service	100	100	100
	Material Flow	Planned production output	100	100	100
	Information Flow	Management Information Integration	100	100	100
	Spare parts	Availability	60	60	100
		Cost	60	100	100
		Reliability of supply	100	100	100
		Quality	100	100	100
		Maximum equipment investment cost			
Processes &	Type of equipment	Flexibility	20	60	100
Technology		Compatibility	60	60	100
		Capability	60	60	100
		Mechanisation	60	100	100
		Automation	20	60	100
		Integration	100	100	100
		Key technologies	20	100	100
		Technological risk	20	60	100
		Setup and changeover requirements	20	100	100
		Maintenance requirements	100	100	100
		Equipment cost	60	100	100
		Availability of associated equipment	20	60	60
		Reliability and after-service	20	60	100
		Ease of learning to use	0	60	60
		Ease of preparation	0	60	100
		Safety	20	60	100
		Ease of installation	0	60	100
		Delivery	0	60	100
		Effect of existing organisation	0	20	60
	Engineering support	Tooling	100	100	100
		Production engineering	100	60	60
	Man-machine interface	Job content	60	60	60
		Skill required	100	100	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Integration	Man-Machine Interface	Customer network	100	100	100
		Degree of management	100	100	100
	Position in chain	Focus	20	60	100
		Make or buy	60	60	100
		Supplier relations	20	20	20
		Distributor relations	20	20	20
		Customer relations	20	20	20
Supplier	Source	Source policy	60	100	100
Relations	Supplier qualification	Supplier qualification means	20	60	100
		Supplier performance measures	60	60	100
		Supplier selection criteria	20	60	100
	Partnership	Types of partnership	20	60	100
		Degree of partnership given to supplier	20	60	100
		Degree of technological cooperation	20	60	100
		Types of communication	20	20	20
	Make or buy	Components identification	20	60	60
		Service degree been bought	20	60	100
Quality Systems	Design quality	Degree of the designed products	60	60	100
	Process quality	Inspection means consistency	100	60	100
		Quality measures	100	100	100
	Total quality	Quality responsibility identification	100	100	100
	Quality levels	Quality levels identification	100	100	100
Human	Cultural properties and				
Resources	Control				
	Labour	Availability	20	60	100
		Suitability	20	60	100
		Salary	100	100	100
		Skill level	20	60	100
	Human and machine interface	Comfortable working height	20	60	100
		Symmetrical movement	60	60	100
		Natural working position	20	60	60
		Adequate working space	20	60	60
		Support of arm and feet	20	60	60
Production	Supplier	Supplier relationship	20	60	100
Planning &	Inventory	Degree of inventory holding	60	60	100
Control		Spare reorder level identification	60	60	100
		Space of inventory holding	60	60	100
	Manufacturing priorities	Methodology of manufacturing priority	60	100	100
		Degree of facilities decentralisation	60	60	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Planning &		Integration of customer requirements changing	100	100	100
Control	Forecasting	Demand forecasting	100	100	100
		Level of investment	20	100	100
	Scheduling	Time horizon for production scheduling	100	100	100
		Policy of resource allocation	60	100	100
		Monitoring measures of scheduling	100	100	100
	Control	Policy of order releasing	60	60	100
		Batch sizes identification	100	100	100
Product	Product details	Degree of scope of products manufactured	60	100	100
Scope &		Focus of the products	60	100	100
New product		Range of products manufactured	60	100	100
Introduction		Stage of product life cycle (Concept, Prototype, Mature, Declining)	100	100	100
		Volume of products manufactured	100	100	100
	Introduction	Rate of new product introduction	60	100	100
		Typical life cycle of product	100	100	100
		Computer aids integration	20	100	100
		Extent of computer assistance	20	100	100
		Innovative new technology	20	100	100
	Lead time	Product design lead time	20	60	60
		Manufacturing lead time	60	100	100
		Product cost (Market prices)	100	100	100
Performance	General	Performance measurement criteria selection	60	100	100
Measurement		Competitive variables focus	60	100	100
		Attitude towards benchmarking	20	60	60
		Strategic performance measures	100	100	100
		Performance data feedback system	100	100	100
		Balance identification between financial and non-financial measures	100	100	100
		Performance information types	100	100	100
		Training of the utilisation of measures	100	100	100
Organisation	Structure	Allocation of the facilities management	100	100	100
		Degree of the centralisation within organisation of manufacturing	60	100	100
		Administrative support of facilities management	100	100	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintainin g Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Organisation	Structure	Degree of product understanding of management	20	60	60
	Functions	Functional emphasis lay within manufacturing organisation	60	100	100
		Degree of management supervision	60	100	100
	Co-ordination	Degree of co-ordination with marketing	20	100	100
		Degree of co-ordination with engineering	100	100	100
		Degree of co-ordination with customers	60	100	100
		Degree of co-ordination with designers	100	100	100
Social	Safety	Safety legislation	100	100	100
	Regional regulation	Environmental regulation	60	100	100
		Safety check control & alert device	80	100	100
		Intrinsic safety design	80	100	100

Appendix E Key Issue Capture Quick Hit Table

Manufacturing system	Issues	Quality	Delivery	Delivery	Design	Volume	Cost/
policy Area			Lead-Time	Reliability	Flexibility	Flexibility	Price
Capacity	Under capacity	0	Reduced	Reduced	0	Reduced	0
	Over capacity	0	Improved	Improved	0	Improved	Reduced
	Rigid capacity	0	0	0	0	Reduced	0
	Bottlenecks	0	Reduced	Reduced	0	Reduced	0
Facilities	Lack of focus	Reduced (?)	Reduced	Reduced	Improved	Improved(?)	0
	Too complex	0	Reduced	Reduced	Improved	Improved	0
	Lack of integration	0	Reduced	Reduced	0	0	0
	Functional lay out	0	Reduced	Reduced	Reduced	0	Reduced(?)
	Lack of capability	Reduced	Reduced(?)	Reduced(?)	Reduced	Reduced	0
Process and technology	Lack of capability	Reduced	Reduced(?)	Reduced(?)	Reduced	Reduced	0
	Lack of flexibility	0	0	0	Reduced	Reduced	0
	Lack of focus	0	0	0	Improved	Improved	0
	Functional lay out	0	Reduced	Reduced	Reduced	0	Reduced(?)
	Long set up times	Reduced(?)	Reduced	Reduced	0	Reduced	Reduced(?)
	No coordination of technology with operations	Reduced	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)
	Low variety, high volume, low integration capability	0	0	0	Improved	Improved	Reduced(?)
	High variety, low volume, high integration capability	0	0	0	Reduced	Reduced	Reduced(?)
	Ageing equipment & technology	Reduced	Reduced(?)	Reduced(?)	0	0	Reduced
Vertical integration	Lack of focus	Reduced(?)	Reduced	Reduced	Reduced(?)	0	0
	Lack of coordination and management	Reduced(?)	Reduced	Reduced	Reduced	Reduced	Reduced
	Low ownership of supply chain	0	Reduced	Reduced	Improved	0	0
	High ownership of supply chain	Improved					
Human Resources	Low workforce skill levels	Reduced	Reduced	Reduced	Reduced	0	Reduced
	Low supervisor skill levels	Reduced	0	Reduecd	0	0	0
	Insufficient motivation	Reduced	Reduced(?)	Reduced	0	0	Reduced(?)
	Inappropriate level of decision making	Reduced(?)	Reduced	Reduced	0	0	0
	Lack of flexibility	0	0	0	Reduced(?)	reduced	0
	Low labour productivity	0	Reduced	Reduced	0	Reduced	Reduced
	Direct labour turnover	Reduced	Reduced(?)	Reduced(?)	Reduced	0	0
	Ageing workforce	Reduced(?)	0	0	0	0	Reduced(?)
	Direct labour absenteeism	0	Reduced(?)	Reduced	0	Reduced(?)	Reduced

Quality Systems	Inappropriate product quality	Reduced	0	0	Reduced(?)	0	Reduced
	Inappropriate process quality	Reduced	Reduced(?)	Reduced	0	Reduced(?)	Reduced
Quality Systems	Inappropriate operations quality	Reduced	Reduced	Reduced	0	0	Reduced
	Scrap and waste material	0	0	0	0	0	Reduced
	Too much quality documentation	Reduced(?)	0	0	0	0	Reduced
	Misunderstood quality procedures	Reduced	0	Reduced	0	0	Reduced(?)
	Lack of workforce involvement in quality	Reduced	0	Reduced(?)	0	0	0
	Lack of ownership of products	Reduced(?)	0	Reduced(?)	0	0	0
	Inspection delays	0	Reduced	Reduced	0	0	0
	Ageing process technology	Reduced	Reduced(?)	Reduced	Reduced(?)	0	0
Planning and control	Inappropriate level of decision making	Reduced(?)	Reduced(?)	0	0	0	Reduced(?)
	Ineffective material control	Reduced	Reduced	Reduced	0	0	Reduced
	High inventories	0	Improved	Improved	Reduced(?)	Improved	Reduced
	Incorrect inventory information	0	Reduced	reduced	0	0	Reduced(?)
	Control system is too complex	0	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced
	High overhead costs	0	0	0	0	0	Reduced
	Frequent expediting	Reduced(?)	0	Reduced(?)	0	0	Reduced
New products and scope	Lack of focus	Reduced(?)	Reduced	Reduced	Improved	0	0
	Too broad a production line	0	Reduced(?)	Reduced(?)	0	0	0
	Too complex	Reduced(?)	Reduced	Reduced(?)	0	0	0
	Introduction too frequent	Reduced(?)	0	Reduced	0	Reduced(?)	Reduced
Performance measurement	Inappropriate measures	Reduced	0	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)
	Poor communication of goals	Reduced	0	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)
	Too complex	Reduced(?)	Reduced(?)	Reduced(?)	0	0	Reduced(?)
Organisation and management	Poor vertical communication	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)
	Poor horizontal communication	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	0	Reduced(?)
	Poor understanding of strategy	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)	Reduced(?)

Note: Key description for each criterion

Reduced: Ability to be competitive is reduced

Reduced(?): Ability to be competitive is possibly reduced

Improved: Ability to be competitive is improved

Improved(?): Ability to be competitive is possibly improved

0: Insignificant effect

Appendix F

PFM Action Plan Selection Table

Action Plans Category	*Details*	*Priority in each category*	*Competitive Criteria*					
			Q	DLT	DR	DF	VF	C/P
Strategy	Link to business strategy		X	X	X	X	X	X
	Define manufacturing strategy		X	X	X	X	X	X
	Activity based costing		X	X	X	X	X	X
Capacity and Facilities	Increase capacity			X	X	X	X	X
	Lead time reduction			X	X			
	Reduce set-up time			X	X		X	X
	Focus factory		X	X		X		X
	Manufacturing re-organisation		X	X			X	X
	Group technology		X		X		X	X
	Improving existing system		X	X	X	X	X	X
	Relocate plant			X	X		X	X
	Close plant			X	X		X	X
	Equipment performance monitoring		X	X	X	X	X	X
	Early Equipment Design & Management		X	X	X	X	X	X
Process and technology	New process, old product		X		X		X	X
	New process, new product		X	X		X		X
	Improve equipment and process technology		X	X	X	X	X	X
	Improve energy/ utilities efficiency							X
	Reduce material losses		X		X		X	X
	Improve equipment utilisation			X	X		X	X
	Increase operations standardisation		X	X		X		X
	Manufacturing mechanisation				X		X	X
	Introduce FMS			X		X		X
	Introduce robots		X	X			X	X
	Introduce material handling				X		X	X
	Introduce CAD			X		X		
	Introduce CAM				X	X	X	
	Increase technical autonomy		X		X		X	
	In-house die and tool design		X	X	X		X	X
	Introduce TPM & RCMX		X	X	X	X	X	X

Action Plans Category	*Details*	*Priority in each category*	*Competitive Criteria* Q	DLT	DR	DF	VF	C/P
Process and technology	Reduce number of variants		X				X	
	Redesign products		X	X		X		X
	Value analysis / product design				X	X	X	
	Design for manufacture		X	X	X	X		X
	Develop product workshops			X		X	X	
	Product introduction ability improvement			X		X		
Information systems	Manufacturing information systems		X	X	X	X	X	X
	Integrated manufacturing information systems		X	X	X	X	X	X
	Maintenance management system			X	X		X	X
	Integrated inter-functional information systems		X	X	X	X	X	X
	Office automation			X		X		X
	Decentralise decision making authority			X	X		X	
	Improve information handling		X	X	X		X	
	Improve communications			X		X	X	
Building	Work environment improvement		X		X		X	X
	External environment improvement			X				X
Planning and Control	Production inventory control systems			X	X		X	X
	Production and inventory control system training		X	X	X		X	
	Just in time manufacture		X	X	X	X	X	X
	Supplier lead time reduction			X	X		X	X
	Reducing provisioning time			X	X	X		X
	Production Scheduling Control			X	X		X	X
Quality systems	Establish total quality control program		X		X			X
	Zero defects		X		X		X	X
	Statistical process control		X		X			
	Quality function deployment		X			X		
	Quality circles		X		X			
	Improve supplier quality		X	X			X	
	Preventative maintenance			X	X		X	X

Action Plans Category	*Details*	*Priority in each category*	*Competitive Criteria*					
			Q	DLT	DR	DF	VF	C/P
Vertical integration	Optimise make versus buy mix			X	X		X	X
	Improve distribution				X		X	X
Human resources	Direct personnel training		X		X	X	X	
	Supervisory training		X			X		
	Manufacturing management education		X		X	X	X	
	Reduce lost work time						X	X
	New wage system							X
	Direct labour motivation			X	X		X	X
	Apply rewards and penalties				X		X	
	Productivity bargaining			X	X		X	X
	Redesign jobs		X	X		X	X	
	Specialise jobs		X			X	X	
	Broad scope of works			X	X	X		
	Involve workers in planning			X	X	X	X	
	Broad planning responsibility		X			X	X	
	Ergonomics		X				X	X
	Worker safety		X					X
	Reduce number of employees				X		X	X
	New skills hiring		X		X		X	X
	Develop a workforce with multiple, flexible skills			X	X	X	X	
	Improve work methods and procedures		X	X	X		X	X
	Implement group work			X	X	X		
	Inter functional work teams		X			X	X	
Organisation	Change labour/management relations		X		X			X
	Encourage employee involvement		X		X	X		
	Improve departmental performance		X			X	X	X
	Change organisational design/focus		X		X	X		
	Improve integration among departments and functions		X	X		X		

Appendix G:

Competitive Criteria versus Product Life Cycle Matrix Table

Corporate strategy requirement		Product/Project Life Cycle				
Item	Competitive criteria	Concept	Design and Development	Production	Decline	Rapid decline
1	Cost / price	•	••	•••	••••	•••••
2	Quality	•••••	•••••	•••••	••••	•••
3	Delivery Reliability	•	•••	••••	•••	•••
4	Delivery Lead Time	•••••	•••••	•••	••	•
5	Design Flexibility	•••••	••••	•••	••	•
6	Volume Flexibility	•••••	••••	•••	••	•

Notes:

1. The symbol of "•••••" means the most important.
2. The symbol of " • " means the least important.
3. This table shows an example analysis about the weight of importance of each competitive criterion with respect to the different stage of a product life cycle or project progressing.
4. The results of this table might be different for a different manufacturing industry. Each manufacturer should choose the proper weight of importance of each criterion to match their manufacturing strategy and objectives. The identification process is done through the discussion of an organised review board. The members of the board should include people from the top management, functional level and operational level.
5. Analysis:
   For quantitative analysis purposes, numbering the weight of importance is better adapted. If each "•" is replaced by the score of "20" and the weight of importance transformed into "%" ratio, this table will be shown as:

Corporate strategy requirement		Product/Project Life Cycle				
Item	Competitive criteria	Concept	Design and Development	Production	Decline	Rapid decline
1	Cost / price	5%	9%	14%	24%	36%
2	Quality	22.5%	22%	24%	24%	21%
3	Delivery Reliability	5%	13%	24%	18%	21%
4	Delivery Lead Time	22.5%	22%	14%	12%	7%
5	Design Flexibility	22.5%	17%	10%	10%	7%
6	Volume Flexibility	22.5%	17%	14%	12%	8%

The percentage of each criterion shows the degree of effort that the company should make during the specified stage of a product life cycle. In real manufacturing environment, the analysis is much more complicated because the company might have more than one product (group); then there is a need for the methodology to assist the complicated mixture and calculation work. Several methodologies were surveyed that can solve this issue: both "Utility Value " and "Analytic Hierarchy Process" can be helpful. In this example the method of "Utility Value" application will be implemented in the following steps.

Appendix H Performance Measure & Indicator Matrix Quick Hit Table

Criteria						Performance	Indicator						
Quality	Delivery Lead Time	Delivery Reliability	Design Flexibility	Volume Flexibility	Cost / Price	Measure	Mean Corrective Time	Breakdown Frequency	Mean Active Maintenance Time	Mean Time Between Maintenance (MTBM)	Mean Time Between Replacement (MTBR)	Mean Down Time (MDT)	Mean Time Between Failure (MTBF)
	P	P	2	2		Maintainability	X	X	X	X	X	X	
P			P		2	Reliability							X
2		P		2	p	Availability		X					
		2		2	P	Labour							
		P	2	2	2	Supportability		X		X	X		
2			P	2	2	Skill							
2		P	2		P	Tooling							
P		2				Calibration		X					
	2	P	P	2	2	Capacity		X					
	2	P	2		2	Construction							
2	2		P			Documentation		X					
			2	2		Dimension							
	2	2		2	2	Space utilisation							
		P		2	P	Productivity		X					
		2		2	2	Lay-out							
		2			2	Location							
					P	Cost Factors		X					
					P	Safety							
P	2	P			P	Quality Factors							
2		P			2	Delivery Achievement		X					

Performance Measure	Set-up Times	Tool Changeover Time	Throughput Time	Failure Rate	Overall Equipment Effectiveness (OEE)	Maintenance Man Hours per System Operating hour (MMH/OH)	Maintenance Man Hours per cycle of System Operation(MMH/cycle)	Maintenance Man Hours per Month (MMH/month)	Maintenance Man Hours per Maintenance Action(MMH/MA)	Utilisation	Equipment Performance Effeciency	Payback period	Maintenance Cost per System Operating Hour
Maintainability						X	X	X	X				X
Reliability				X									
Availability	X	X			X	X	X				X		
Labour	X	X	X			X	X	X	X	X			
Supportability	X										X		X
Skill	X		X										
Tooling		X								X			
Calibration													
Capacity	X	X	X						X	X	X		
Construction													
Documentation	X		X							X	X		
Dimension													
Space utilisation										X			
Productivity	X	X	X							X	X		
Lay-out													
Location													
Cost Factors	X		X						X		X	X	X
Safety													
Quality Factors													
Delivery Achievement	X		X										

Performance Measure	Maintenance Cost per Month	Maintenance Cost per Year	Total maintenance Cost / Equipment Replacement Cost	Total Maintenance Cost / Total Life Cycle Cost		Quality Rate	Productivity	Net Present Value (NPV)	Overall Availability	Not Right First Time	Stock Turns	Promised Date Compliance	Value Added per Person
Maintainability	X	X	X	X							X		
Reliability						X							
Availability						X	X		X		X		
Labour							X						
Supportability	X	X	X	X		X	X		X		X	X	
Skill													
Tooling											X		
Calibration						X							
Capacity						X	X						
Construction													
Documentation						X			X			X	
Dimension													
Space utilisation													
Productivity							X				X		
Lay-out													
Location													
Cost Factors	X	X	X	X		X	X	X			X	X	X
Safety													
Quality Factors										X		X	
Delivery Achievement												X	

Performance / Measure	Floor Space Utilisation	New Product Introduction Time	Utility Consumption	
Maintainability				
Reliability				
Availability				
Labour				
Supportability				
Skill		X		
Tooling		X		
Calibration				
Capacity	X	X		
Construction	X			
Documentation	X	X		
Dimension	X			
Space utilisation	X			
Productivity	X	X		
Lay-out	X			
Location	X			
Cost Factors	X	X		
Safety				
Quality Factors				
Delivery Achievement		X		

Notes:

1. There are two goals in utilisation this table.

- For existing equipment, the performance measure which is assessed in this table can indicate the present operation in its life cycle of each equipment.
- For new equipment acquisition, these measures are important decision-making factors in biding. In the following operation stage after acquisition, these factors are required to build up maintenance plan.

2. **Reliability** – Reliability can be defined as the probability that a system or product will perform in a satisfactory manner for a given period of time when it is used under specified operating conditions. The measures to be concerned in reliability prediction are:

   <1> **Failure rate (λ)**: λ is expressed as:

$$\lambda = \frac{Number\ of\ Failures}{Total\ Operating\ Hours}$$

   <2> Reliability is also used as a measure of the frequency of downtime, or **Mean Time Between Failures (MTBF)**. It is determined by:

$$\mathrm{Re}liability = MTBF = \frac{Total\ operating\ time}{Number\ of\ failures}$$

$$\mathrm{Re}liability = MTBF = \frac{Total\ operating\ cycles\ (km, tons)}{Number\ of\ failures}$$

3. **Maintainability** – Maintainability is the measure of the ability to make equipment available after it has failed. Some of the typical measures related to maintainability prediction are:

   <1>**Mean corrective time ($\overline{Mct}$):** Each time that a system fails, a series of steps are required to repair or restore the system to its full operational status. The mean corrective maintenance time ($\overline{Mct}$), or the mean time to repair (MTTR) which is equivalent is a composite value representing the arithmetic average of these individual maintenance cycle times.

$$\overline{M}_{ct} = \frac{\sum_{i=1}^{n} Mct_i}{n} = MTTR$$

   Where Mct_i is the total active corrective maintenance cycle time for each maintenance action and "n" is the sample size.

   <2>**Mean preventative maintenance time ($\overline{Mpt}$)**: $\overline{Mpt}$ is the mean elapsed time to perform preventative or scheduled maintenance on an item, and it is expressed as:

$$\overline{M}pt = \frac{\sum (fpt_i)(Mpt_i)}{\sum fpt_i}$$

where fpt_i is the frequency of the individual (ith) preventative maintenance action in actions per system operating hour, and Mpt_i is the elapsed time required for the (ith) preventative maintenance action.

<3>**Mean active maintenance time**($\overline{M}$): $\overline{M}$ is the mean or average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance. It excludes logistics delay time (LDT) and administrative delay time (ADT) and is expressed as:

$$\overline{M} = \frac{(\lambda)(\overline{M}ct) + (fpt)(\overline{M}pt)}{\lambda + fpt}$$

where λ is the corrective maintenance rate or failure rate, and fpt is the preventative maintenance rate.

<4>**Maintenance downtime** (MDT): MDT constitutes the total elapsed time required (when the system is not operational) to repair and restore a system to full operating status, and/or to retain a system in that condition. MDT includes mean active maintenance time, logistics delay time (LDT), and administrative delay time (ADT).

<5>**Mean time between maintenance** (MTBM): MTBM is the elapsed time between maintenance actions (corrective and preventative maintenance) and can be expressed as:

$$MTBM = \frac{1}{1/MTBM_u + 1/MTBM_s}$$

where $MTBM_u$ is the mean interval of unscheduled (corrective) maintenance and $MTBM_s$ is the mean interval of scheduled (preventative) maintenance.

<6>**Mean time between replacement** (MTBR): MTBR is the mean time between item replacement and is a major parameter in determining spare-time requirements. A maintainability objective in system design is to maximise MTBR where feasible.

4. **Maintenance labour hour factors**: When considering measures of maintainability, it is necessary to consider labour-time elements as well. Typical labour-time factors are:
<1> Maintenance man hours per system operating hours (MMH/OH)
<2> Maintenance man hours per cycle of system operation (MMH/cycle)
<3> Maintenance man hours per month (MMH/month)
<4> Maintenance man hours per maintenance action (MMH/MA)
<5> All mean values of these factors

5. **Maintenance cost factors**: Maintainability is directly concerned with the characteristics of system design that will ultimately result in the accomplishment of maintenance at minimising overall cost. There are some important cost-related criteria in the system design:

<1> Cost per maintenance action
<2> Maintenance cost per system operating hour
<3> Maintenance cost per month
<4> Maintenance cost per order
<5> The ratio of maintenance cost to total life-cycle cost

6. Availability factors : Availability is a measure of uptime, as well as the duration of downtime. The term availability is always used as a measure of system readiness, i.e. the degree, percent or probability that a system will be ready or available when it is required for use. The factors of availability are:

<1> Operational availability – Operational availability is the probability that a system or equipment when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. It is described as:

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Where the MTBM is the mean time between maintenance, the MDT is the mean maintenance downtime

<2> Overall Availability

$$Availability = \frac{Scheduled\ time - All\ unplanned\ time}{Scheduled\ time}$$

7. Overall Equipment Effectiveness – Overall Equipment Effectiveness is an overall measure that considers uptime, speed, and precision. It is measured as a product of:

$$Overall\ Equipment\ Effectiveness\ (OEE) = Overall\ availability * Process\ rate * Quality\ rate$$

8. Process rate – Process rate is a measure of the ability of the equipment to operate at a standard speed or cycle. It is calculated by:

$$Process\ rate = \frac{Ideal\ cycle\ time}{Actual\ cycle\ time}$$

9. Quality rate – Quality rate is a measure of the ability of the equipment to produce to a standard product quality. It is measured by:

$$Quality\ rate = \frac{Quality\ Product}{Total\ product\ produced}$$

10. NPV – Net Present Value, i.e. the net economic value of present equipment after estimated years

$$NPV = \left(\sum_{n=1}^{L} \frac{I_n - E_n}{(1+i)^n} \right) + \frac{S_L}{(1+i)^L}$$

where

$NPV = Net\ present\ value$

$I_n = Income\ for\ year\ n$

$E_n = Expenditure\ for\ year\ n$

$i = Discount\ rate$

$L = Life\ of\ equipment\ or\ number\ of\ years\ being\ considered$

$S_L = Sale\ or\ scrap\ value\ at\ end\ of\ life,\ i.e.\ year\ n$

Appendix I

Production Facilities Management Decision-Making Assessment Quick Hit Table

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Capacity	Total capacity	Market and demand structure	20	60	100
		Floor space	20	100	100
		Plant/equipment size	20	60	100
		Equipment availability	20	60	100
		Availability of manpower	60	60	60
		Availability of cash	20	100	100
	Variation Satisfaction	Degree of flexibility	20	60	100
	Expand Methods	How	0	60	100
		Size of increment	0	60	100
	Contraction method	How	0	60	100
		Size of contraction	0	60	100
	Timing	When to expand or contract	0	60	100
	Bottleneck	Productivity	60	60	100
	Demand Forecasting	Required quantity	60	60	100
		How monitor	100	60	60
		How forecast	100	60	60
Facilities	Number	Number of equipment	60	60	100
	Specification	Size	60	100	100
		Capability	100	100	100
		Utilities	20	60	100
	Location	Proximity to market	20	60	100
		Integration with the organisation	20	60	100
		Availability of labour and skills	60	60	100
		Availability of amenities	20	60	100
		Availability of transport	60	60	100
		Availability of input	20	60	100
		Availability of services	20	60	100
		Suitability of land and climate	20	60	100
		Regional regulation	20	20	60
		Room for expansion	20	60	60
		Safety requirement	60	60	60
		Political, cultural and economic situation	20	20	60
		Special grants, regional taxes and import / export barriers	20	20	60
		Plant layout	60	60	100
		Fuel or energy, availability and cost	60	60	100
	Lay-out	Maximum flexibility	20	60	100
		Maximum co-ordination	20	60	100
	Function Integration	Enterprise	60	60	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Facilities		Maximum visibility	20	60	100
		Minimum distance	60	100	100
		Minimum handling	60	100	100
		Inherent safety	20	60	60
		Efficient process flow	20	60	100
		Identification	20	60	60
	Focus / Specialisation	Type	20	60	100
	Function Integration	Enterprise	60	60	100
		Manufacturing	100	100	100
		Support Service	100	100	100
	Material Flow	Planned production output	100	100	100
	Information Flow	Management Information Integration	100	100	100
	Spare parts	Availability	60	60	100
		Cost	60	100	100
		Reliability of supply	100	100	100
		Quality	100	100	100
		Maximum equipment investment cost			
Processes & Technology	Type of equipment	Flexibility	20	60	100
		Compatibility	60	60	100
		Capability	60	60	100
		Mechanisation	60	100	100
		Automation	20	60	100
		Integration	100	100	100
		Key technologies	20	100	100
		Technological risk	20	60	100
		Setup and changeover requirements	20	100	100
		Maintenance requirements	100	100	100
		Equipment cost	60	100	100
		Availability of associated equipment	20	60	60
		Reliability and after-service	20	60	100
		Ease of learning to use	0	60	60
		Ease of preparation	0	60	100
		Safety	20	60	100
		Ease of installation	0	60	100
		Delivery	0	60	100
		Effect of existing organisation	0	20	60
	Engineering support	Tooling	100	100	100
		Production engineering	100	60	60
	Man-machine interface	Job content	60	60	60
		Skill required	100	100	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Integration	Man-Machine Interface	Customer network	100	100	100
		Degree of management	100	100	100
	Position in chain	Focus	20	60	100
		Make or buy	60	60	100
		Supplier relations	20	20	20
		Distributor relations	20	20	20
		Customer relations	20	20	20
Supplier	Source	Source policy	60	100	100
Relations	Supplier qualification	Supplier qualification means	20	60	100
		Supplier performance measures	60	60	100
		Supplier selection criteria	20	60	100
	Partnership	Types of partnership	20	60	100
		Degree of partnership given to supplier	20	60	100
		Degree of technological cooperation	20	60	100
		Types of communication	20	20	20
	Make or buy	Components identification	20	60	60
		Service degree been bought	20	60	100
Quality Systems	Design quality	Degree of the designed products	60	60	100
	Process quality	Inspection means consistency	100	60	100
		Quality measures	100	100	100
	Total quality	Quality responsibility identification	100	100	100
	Quality levels	Quality levels identification	100	100	100
Human	Cultural properties and				
Resources	Control				
	Labour	Availability	20	60	100
		Suitability	20	60	100
		Salary	100	100	100
		Skill level	20	60	100
	Human and machine interface	Comfortable working height	20	60	100
		Symmetrical movement	60	60	100
		Natural working position	20	60	60
		Adequate working space	20	60	60
		Support of arm and feet	20	60	60
Production	Supplier	Supplier relationship	20	60	100
Planning &	Inventory	Degree of inventory holding	60	60	100
Control		Spare reorder level identification	60	60	100
		Space of inventory holding	60	60	100
	Manufacturing priorities	Methodology of manufacturing priority	60	100	100
		Degree of facilities decentralisation	60	60	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Planning &		Integration of customer requirements changing	100	100	100
Control	Forecasting	Demand forecasting	100	100	100
		Level of investment	20	100	100
	Scheduling	Time horizon for production scheduling	100	100	100
		Policy of resource allocation	60	100	100
		Monitoring measures of scheduling	100	100	100
	Control	Policy of order releasing	60	60	100
		Batch sizes identification	100	100	100
Product	Product details	Degree of scope of products manufactured	60	100	100
Scope &		Focus of the products	60	100	100
New product		Range of products manufactured	60	100	100
Introduction		Stage of product life cycle (Concept, Prototype, Mature, Declining)	100	100	100
		Volume of products manufactured	100	100	100
	Introduction	Rate of new product introduction	60	100	100
		Typical life cycle of product	100	100	100
		Computer aids integration	20	100	100
		Extent of computer assistance	20	100	100
		Innovative new technology	20	100	100
	Lead time	Product design lead time	20	60	60
		Manufacturing lead time	60	100	100
		Product cost (Market prices)	100	100	100
Performance	General	Performance measurement criteria selection	60	100	100
Measurement		Competitive variables focus	60	100	100
		Attitude towards benchmarking	20	60	60
		Strategic performance measures	100	100	100
		Performance data feedback system	100	100	100
		Balance identification between financial and non-financial measures	100	100	100
		Performance information types	100	100	100
		Training of the utilisation of measures	100	100	100
Organisation	Structure	Allocation of the facilities management	100	100	100
		Degree of the centralisation within organisation of manufacturing	60	100	100
		Administrative support of facilities management	100	100	100

Manufacturing System Management Policy Area	Decision	Sub-Decision	Production Facilities Management Options Choices		
			Maintaining Existing Facilities	Enhancing Existing Facilities	Replacing Existing Systems
Organisation	Structure	Degree of product understanding of management	20	60	60
	Functions	Functional emphasis lay within manufacturing organisation	60	100	100
		Degree of management supervision	60	100	100
	Co-ordination	Degree of co-ordination with marketing	20	100	100
		Degree of co-ordination with engineering	100	100	100
		Degree of co-ordination with customers	60	100	100
		Degree of co-ordination with designers	100	100	100
Social	Safety	Safety legislation	100	100	100
	Regional regulation	Environmental regulation	60	100	100
		Safety check control & alert device	80	100	100
		Intrinsic safety design	80	100	100

Appendix J

Dear Sir/Madam:

Questionnaire for Production Facilities Management (PFM)

I am building a framework which aims to help with management decisions about when to maintain, enhance or replace production facilities. I have reached the stage where the framework, including a proposed implementation workbook, is complete. I am now seeking practical input from industry:

1) To test the framework with real data.
2) To ensure that the framework uses appropriate performance measures.

Please can you help to:

1) Answer the enclosed questionnaire about performance measures and return in the enclosed envelope by the **1st November 1999**
2) Test the framework in your company. This will involve me in discussion for about 3-4 hours with people who are responsible for your production facilities and equipment maintenance, enhancement and replacement decisions.
3) The visiting of the test is expected to take place between 10th-20th November 1999, if that will be available.

A final survey report will be produced before the end of this year and each participant will receive a complimentary copy. I do hope you will be able to take part.

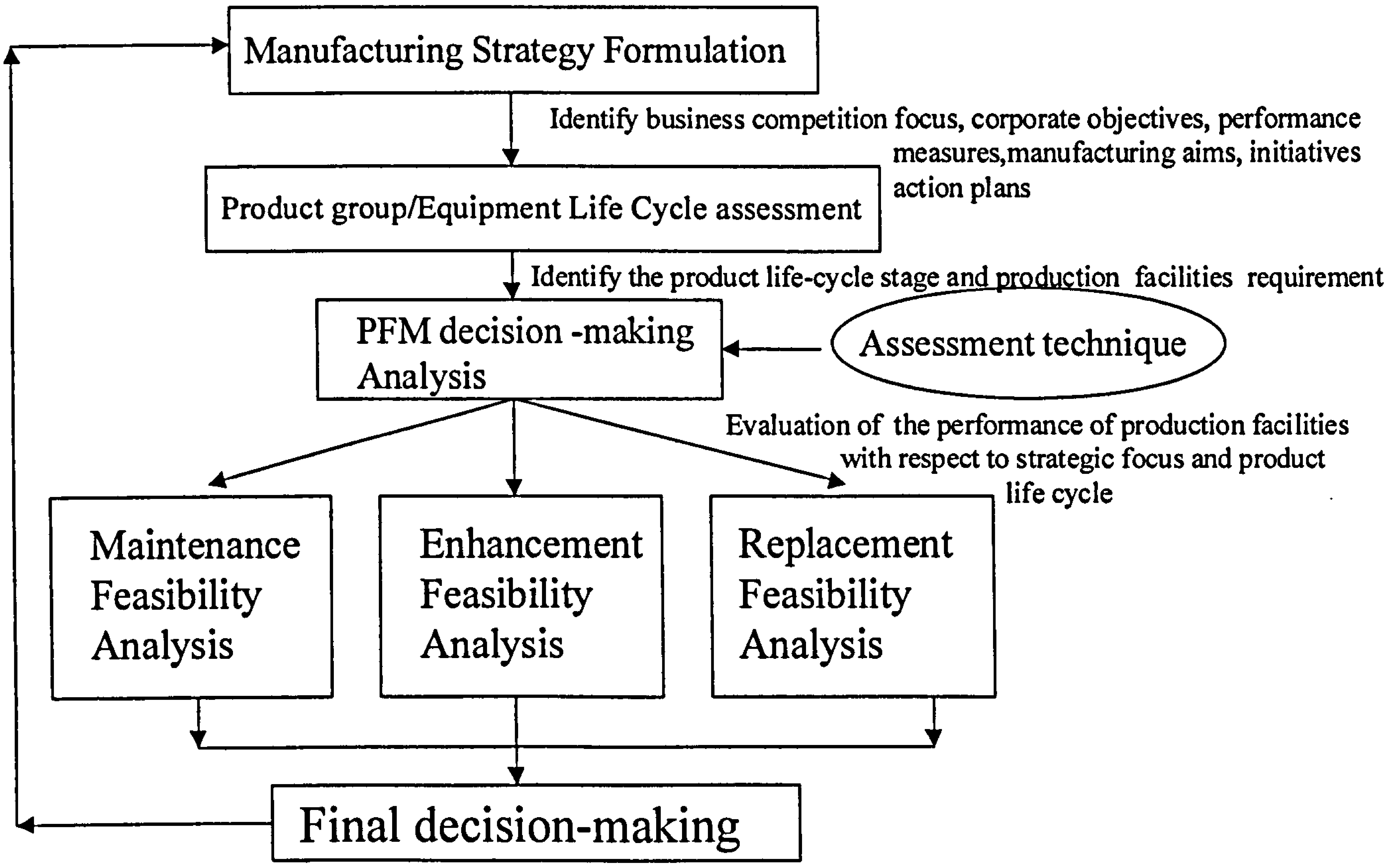
Thank you in anticipation.

Yours sincerely!

Wei-Chung Liu
Manufacturing Systems Department
School of Industrial and Manufacturing Science
Cranfield University

Appendix K

Questionnaire for Production facilities Management (PFM)



Overall Flow of Strategically Driven Production Facilities Management Framework

Company Information

Respondent's Name: ______________________ Position: ______________________

Company Name: ____

Company Address: ____

____

Question 1: Do you apply any of the following strategies in your business? You may tick more than one in the box

Management Strategy/ Methodology	Used Currently	Not used currently	
		but will use it in the future	and I am not aware of it
JIT (Just-in-Time)			
MRP (Material Requirement Planning)			
MRP II (Material Resource Planning)			
RCM (Reliability Centred Maintenance)			
TPM (Total Productive Maintenance)			
TQM (Total Quality Management)			
WCM (World Class Manufacturing)			
Lean Manufacturing			
ILS (Integrated Logistics Support)			
BPR (Business Process Reengineering)			
CE (Concurrent Engineering)			
CALS (Continuous Acquisition and Logistics Support)			
CMMS (Computerised Maintenance Management System)			
Others (please specify)			

Question 2: In formulating your manufacturing strategy, which of the following areas do you consider?

Policy areas	Please tick
Capacity	Yes / No
Facilities	Yes / No
Process and Technology	Yes / No
Vertical Integration	Yes / No
Supplier Relations	Yes / No
Human Resources	Yes / No
Quality Systems	Yes / No
Production Planning and Control	Yes / No
New Product Introduction and Scope	Yes / No
Performance Measurement	Yes / No
Organisation	Yes / No
Others (please specify)	

Question 3: Do you use any of the following criteria to monitor your business competitiveness? Please tick the box.

Competitive Criteria	I use		If "Yes", can you tell the weight of importance for each criterion				
	Yes	No	Negligible	Low	Acceptable	High	Very High
Quality							
Delivery Reliability							
Delivery Lead Time							
Design Flexibility							
Volume Flexibility							
Cost							
Price							
Speed							
Others (please specify)							

Question 4: Do you use the following parameters in your facilities/equipment management decisions? Please tick in the appropriate boxes.

Performance Measures (P.M.) Category	Performance Indicators (P.I.)	I use	If "Yes", can you tell the weight of importance in decision-making		
			Low	Middle	High
Quality	Quality Rate	Yes / No	L	M	H
	Monthly scrap cost	Yes / No	L	M	H
	Monthly rework cost	Yes / No	L	M	H
	Weekly process yield (%)	Yes / No	L	M	H
	Rate of customer complaints on services	Yes / No	L	M	H
	Warranty claims	Yes / No	L	M	H

Availability	Equipment Availability	Yes / No	L	M	H
	Equipment Breakdown Frequency	Yes / No	L	M	H
	Replacement Frequency	Yes / No	L	M	H

Capacity	Output/Throughput per Machine hour	Yes / No	L	M	H
	Overall Equipment Effectiveness (OEE)	Yes / No	L	M	H
	Percentage of full capacity normally available	Yes / No	L	M	H
	Capacity Ratio (actual hours worked / budgeted standard hours)	Yes / No	L	M	H
	Machine hours / year	Yes / No	L	M	H
	Utilisation (Actual output / designed capacity)	Yes / No	L	M	H
	Efficiency (Actual output / effective capacity)	Yes / No	L	M	H

Cost	Total Variable Cost / Total Sales	Yes / No	L	M	H
	Total Fixed Cost / Total Sales	Yes / No	L	M	H
	Cost per Operation Hour	Yes / No	L	M	H
	Monthly Production Cost per Pound	Yes / No	L	M	H
	Utility Consumption	Yes / No	L	M	H
	Life cycle cost of equipment	Yes / No	L	M	H
	Payback Period of each machine	Yes / No	L	M	H

Delivery	Percentage of work/jobs/customer delivered on time	Yes / No	L	M	H
	Minimum delivery time/average delivery time	Yes / No	L	M	H
	Percentage of orders delivered late	Yes / No	L	M	H
	Schedule adherence	Yes / No	L	M	H

Reliability	Failure Rate	Yes / No	L	M	H
	Mean Time Between Failure (MTBF)	Yes / No	L	M	H

Facilities	Set-up times for each machine	Yes / No	L	M	H
	Throughput time of each machine	Yes / No	L	M	H
	Expected life of machine	Yes / No	L	M	H
	Floor space utilisation	Yes / No	L	M	H
	Percentage of utilised/occupied space	Yes / No	L	M	H

Continued Question 4:

Performance Measures (P.M.) Category	Performance Indicators (P.I.)	I use	Weight of importance		
			Low	Middle	High
Flexibility	Monthly average changeover time	Yes / No	L	M	H
	Time-to-Market for a new product	Yes / No	L	M	H
	Variety of product and services	Yes / No	L	M	H
	Machine change-over time	Yes / No	L	M	H
	Average capacity and maximum capacity	Yes / No	L	M	H
	Average lot size	Yes / No	L	M	H

Maintainability	Mean Down Time (MDT)	Yes / No	L	M	H
	Mean Time To Repair (MTTR)	Yes / No	L	M	H
	Mean Time Between Maintenance (MTBM)	Yes / No	L	M	H
	Mean Time Between Replacement (MTBR)	Yes / No	L	M	H
	Logistics Delay Time (LDT)	Yes / No	L	M	H
	Administrative Delay Time (ADT)	Yes / No	L	M	H
	Mean preventive maintenance time	Yes / No	L	M	H
	Mean active correction maintenance time	Yes / No	L	M	H
	Monthly unscheduled downtime percentage	Yes / No	L	M	H
	Monthly scheduled downtime percentage	Yes / No	L	M	H
	Monthly machine usage (%)	Yes / No	L	M	H
	Monthly plant run time (%)	Yes / No	L	M	H
	Utilisation of maintenance personnel	Yes / No	L	M	H

Financial	Profit per year	Yes / No	L	M	H
	Net Added Value	Yes / No	L	M	H
	Labour productivity	Yes / No	L	M	H
	Operation costs	Yes / No	L	M	H
	Materials	Yes / No	L	M	H
	Sales	Yes / No	L	M	H
	Depreciation	Yes / No	L	M	H

Productivity	Net output per employee	Yes / No	L	M	H
	Sales/capital employed	Yes / No	L	M	H
	Sales/fixed assets	Yes / No	L	M	H
	Sales/employee	Yes / No	L	M	H

Inventory	Inventory turnover rates	Yes / No	L	M	H
	Rate of change of inventory levels	Yes / No	L	M	H
	Average customer or input queue length or waiting time	Yes / No	L	M	H
	Capital tied up in stock	Yes / No	L	M	H
	Inventory / Sales	Yes / No	L	M	H

Speed	Customer query time	Yes / No	L	M	H
	Order lead time	Yes / No	L	M	H
	New production introduction time	Yes / No	L	M	H
	Cycle time	Yes / No	L	M	H

Continued Question 4:

Performance Measures (P.M.) Category	Performance Indicators (P.I.)	I use	Weight of importance		
			Low	Middle	High
Labour	Value added per work hour	Yes / No	L	M	H
	Maintenance man hours / month	Yes / No	L	M	H
	Maintenance man hour / operating hour	Yes / No	L	M	H
Safety	Monthly total incident rate	Yes / No	L	M	H
	Annual Accident Rates	Yes / No	L	M	H
Others (Please specify)					

Question 5: Is there anything else that you would like to add that relates to how you link your production facilities management to your business strategy?" Please use the space below.

____

____

____

____

____

Question 6: I hope to visit your company to test the framework. Would you be prepared for me to visit you?

Yes ☐ No ☐

If "Yes", please provide the information:

Personnel to contact:

Name: ____

Department: ____

Contact Tel: ____________________ Fax: ______________________

Your contribution to this research is greatly appreciated. Please, put the questionnaire in the enclosed addressed envelope and send to:

Wei-Chung, Liu

Cranfield University, Building 30, School of Industrial and Manufacturing Science, Cranfield, Bedfordshire, MK43 OAL

You can also contact me by:

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Appendix L Questionnaire Survey Results

Question 1: Strategies/methodologies utilised in business

Strategy / Methodology Utilised	Used Currently	Will use in the future	Not aware at the moment	None
TQM (Total Quality Management)	10			2
JIT (Just In Time)	8	2		2
Lean Manufacturing	7		2	3
TPM (Total Productive Maintenance)	6	1	1	4
WCM (World Class Manufacturing)	6		1	5
CMMS (Computerised Maintenance Management System)	5	1		6
MRP (Material Requirement Planning)	4	1		7
MRPII (Manufacturing Resource Planning)	4	3		5
BPR (Business Process Reengineering)	4	1	1	6
CE (Current Engineering)	2	2	1	7
OPT (Optimised Production Technology)	1	2	3	6
CALS (Continuous Acquisition and Logistics Support)	1	1	4	6
GT (Group Technology)	1		3	8
AMT (Advanced Manufacturing Technology)	1		3	8
RCM (Reliability Centred Maintenance)		2	1	9
ILS (Integrated Logistics Support)		1	3	8

Note:

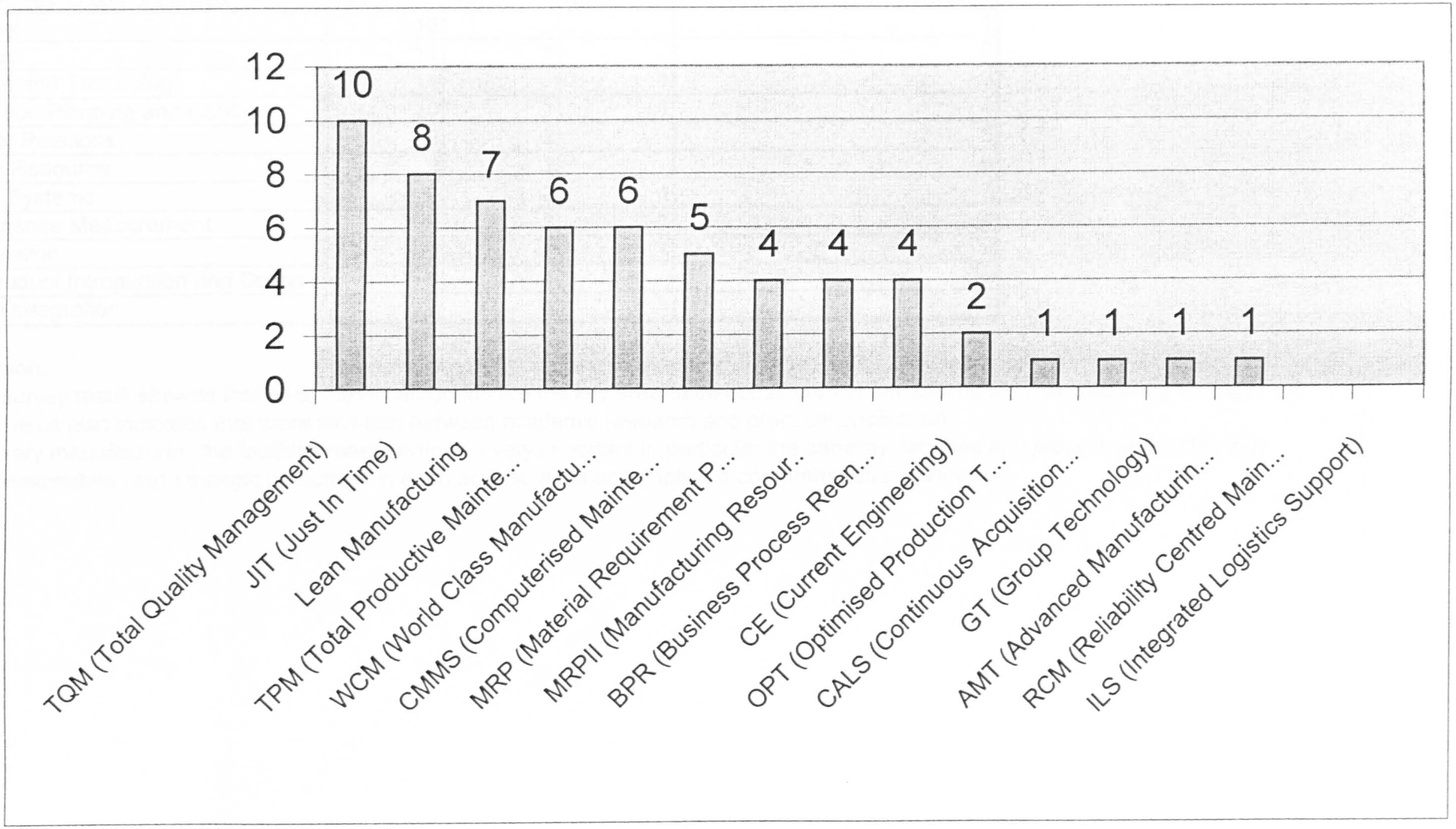
1. Companies answered the questionnaire: 12
2. Companies have been visited: 3 in U.K. and 3 in Taiwan
3. Number of companies invited: 161
4. Number of companies returned directly: 8
5. Number of companies didn't answer the questionnaire due to the company's policy: 7
6. The rate of answering the questionnaire is rather low but interview and discussion of the developed model received considerable value.

Discussion:

1. From the top two strategies that manufacturing industry focused are the TQM and JIT, which matches with the quality and cost are the most important measures amongst competitive criteria.
2. The application of Information Technology is getting more important; especially on the production facilities management. However, there is still lack of development and application of the CMMS (Computerised Maintenance Management System) to assist the facilities management.
3. The management on maintenance of the existing facilities will become one of the important topics to be cared due to it is directly related to the cost of capital investment.

Appendix L Questionnaire Survey Results

Question 1: Strategies/methodologies utilised in business



Appendix L Questionnaire Survey Results

Question 2: Policy areas in strategy formulation

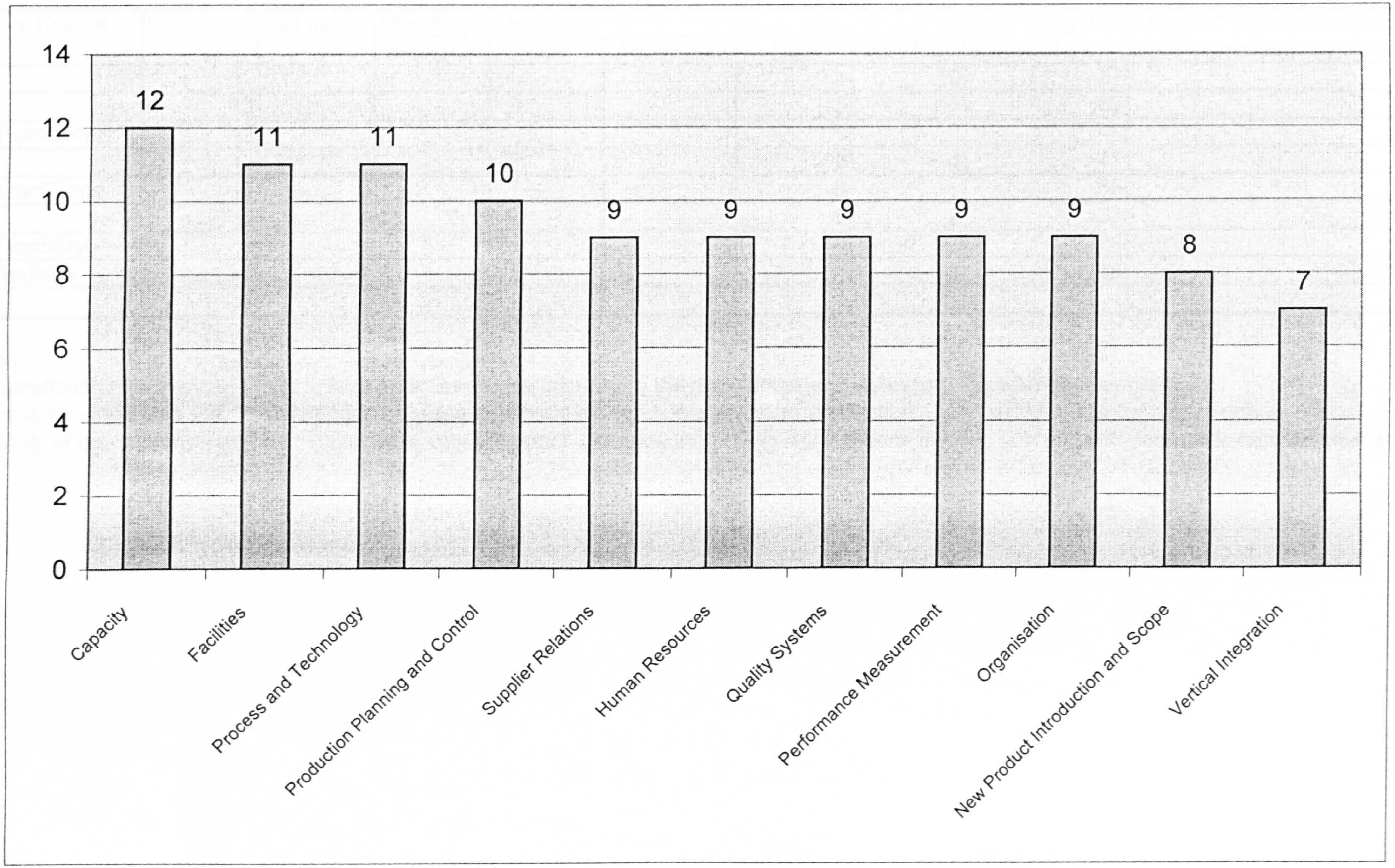
Policy Areas to be concerned	Yes	No	None	Priority in strategy formulation
Capacity	12			1
Facilities	11	1		2
Process and Technology	11		1	3
Production Planning and Control	10	1	1	4
Supplier Relations	9	3		5
Human Resources	9	3		6
Quality Systems	9	2	1	7
Performance Measurement	9	2	1	8
Organisation	9	2	1	9
New Product Introduction and Scope	8	4		10
Vertical Integration	7	4	1	11

Discussion:

1. The survey result showes that all of these categories are the key area to be considered in formulating the manufacturing strategy.
2. This result also indicates that there isn't gap between academic research and practical application.
3. To every manufacturer, the facilities management is very important in particular the capacity, facilities and process and technology.
4. It is reasonableto set strategic objectives in each area so as to accomplish a comprehensive strategy.

Appendix L Questionnaire Survey Results

Question 2: Policy areas in strategy formulation



Appendix L Questionnaire Survey Results

Question 3: Business competitiveness criteria utilisation

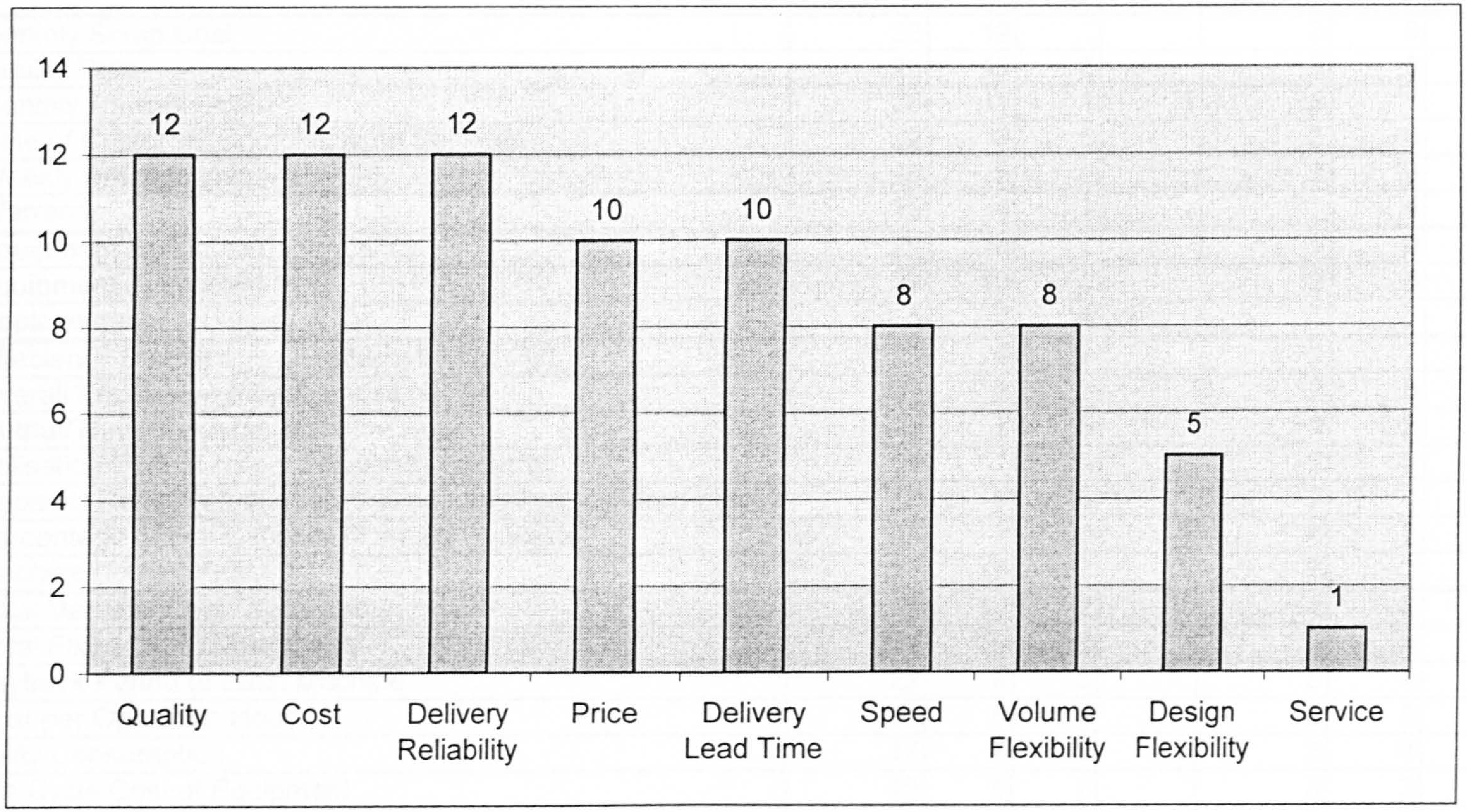
Competitive Criteria	Use	Not use	Weight of importance					Total Weight of Each Criterion	Priority of the importance of Each Competitive Criterion
			Negligible	Low	Acceptable	High	Very high		
Quality	12				1	1	10	57	1
Cost	12				1	5	6	53	2
Delivery Reliability	12				1	9	2	49	3
Price	10	2			3	3	4	41	4
Delivery Lead Time	10	2		1	3	6		35	5
Speed	8	4			1	5	2	33	6
Volume Flexibility	8	4			4	4		28	7
Design Flexibility	5	7			3	1	1	18	8
Service	1					1		4	9

Discussion:

1. From questionnaire survey and face to face interview, these criteria are the popular ones in assessing the business performance.
2. This result also indicates that there isn't gap between academic research and practical application.
3. The priority of the importance of each criterion is very important because the priority will influence the decision and sub decision in facilities management.

Appendix L Questionnaire Survey Results

Question 3: Business competitiveness criteria utilisation



Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Quality	Monthly Scrap Cost	33	12			3	9	1
	Quality Rate	28	10	2		2	8	2
	Monthly Rework Cost	28	11	1	1	3	7	3
	Rate of Customer Complaints on Services	22	7	5		2	6	4
	Weekly Process Yield	16	6	6		2	4	5
	Warranty Claims	12	4	7			4	6
Availability	Equipment Breakdown Frequency	29	10	2		1	9	1
	Equipment Availability	28	10	2		2	8	2
	Replacement Frequency	5	2	8		1	1	3
Capacity	Effeciency (Actual output / effective capacity)	25	9	3		2	7	1
	Overall Equipment Effectiveness (OEE)	22	8	3		2	6	2
	Output/Throughput per Machine Hour	21	7	5		3	5	3
	Utilisation (Actual output / designed capacity)	19	7	5		2	5	4
	Capacity Ratio (Actual hours wirked / bugeted standard hours)	16	6	6		2	4	5
	Percentage of Full Capacity Normally Available	15	7	5	1	4	2	6
	Machine hours / Year	11	5	7	1	2	2	7
Cost	Total Variable Cost / Total Sales	23	10	2		4	5	1
	Total Fixed Cost / Total Sales	22	10	2		5	4	2
	Payback Period of Each Machine	22	9	3		5	4	3
	Cost per Operation Hour	21	8	4		3	5	4
	Utility Consumption	17	7	5	1	2	4	5
	Life Cycle Cost of Equipment	12	5	7		3	2	6
	Monthly Production Cost per Pound	9	4	8	1	1	2	7
Delivery	Percentage of Work/Job/Customer Delivered On Time	29	10	2		1	9	1
	Schedule Adherence	27	10	2		3	7	2
	Minimum Delivery Time / Average Delivery Time	16	7	5	1	3	3	3
	Percentage of Orders Delivered Late	15	6	6		3	3	4
Reliability	Failure Rate	26	9	3		1	8	1
	Mean Time Between Failure (MTBF)	10	4	8		2	2	2
Facilities	Throughput Time of Each Machine	26	10	2	1	2	7	1

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Financial	Set-up Time for Each Machine	25	10	2	1	3	6	2
	Expected Life of Machine	14	6	6		4	2	3
	Floor Space Utilisation	11	6	6	1	5		4
	Percentage of Utilised / Occupied Space	9	5	7	2	2	1	5
Flexibility	Machine Changeover Time	21	9	3		3	5	1
	Average Lot Size	16	8	4	2	4	2	2
	Time-To-Market for a New Product	14	6	6	1	2	3	3
	Variety of Product and Services	10	4	8		2	2	4
	Average Capacity and Maximum Capacity	9	5	7			3	5
	Monthly Average Changeover Time	9	4	8		3	1	6
Maintainability	Mean Down Time (MDT)	20	8	5	1	2	5	1
	Mean Time Between Maintenance (MTBM)	18	5	7			6	2
	Monthly Plant Up Time (%)	16	6	6		2	4	3
	Mean Time To Repair (MTTR)	15	5	7		3	3	4
	Mean Preventive Maintenance Time	15	6	6		3	3	5
	Monthly Unscheduled Downtime Percentage	15	6	6		3	3	6
	Monthly Machine Uptime (%)	15	6	6	1	1	4	7
	Mean Time Between Replacement (MTBR)	14	4	8		1	4	8
	Utilisation of Maintenance Personnel	12	5	7		3	2	9
	Monthly Scheduled Downtime Percentage	9	5	6		3	1	10
	Mean Active Correction Maintenance Time	9	3	9		3	1	11
	Logistics Delay Time (LDT)	8	2	10		4		12
	Administrative Delay Time (ADT)	8	2	10		4		13
Financial	Profit per Year	30	10	2			10	1
	Materials	27	10	2		3	7	2
	Sales	25	9	3		2	7	3
	Labour Productivity	24	10	2	1	1	7	4
	Operation Costs	24	9	3		3	6	5
	Depreciation	21	9	3	1	4	4	6
	Net Added Value	15	6	6		3	3	7
Productivity	Net output per Employee	33	11	1			11	1
	Sales / Capital employeed	24	9	3		3	6	2
	Sales / Employee	22	8	4		2	6	3
	Sales / Fixed Assets	18	6	6			6	4

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Inventory	Inventory Turnover Rates	31	12		1	3	8	1
	Capital Tied Up In Stock	29	11	1		4	7	2
	Inventory / Sales	21	8	3		3	5	3
	Rate of Change of Inventory Levels	21	9	3	1	4	4	4
	Average Customer or Input Queue Length or Waiting Time	7	3	9		2	1	5
Speed	Cycle Time	22	8	4	1		7	1
	Order Lead Time	19	7	5		2	5	2
	New Production Introduction Time	17	7	5	1	2	4	3
	Customer Query Time	13	5	7		2	3	4
Labour	Value Added Per Work Hour	17	6	6		1	5	1
	Maintenance Man Hours / Month	10	4	8		2	2	2
	Maintenance Man Hour / Operating Hour	10	4	8		2	2	3
Safety	Annual Accident Rates	31	11	1		2	9	1
	Monthly Total Incident Rate	31	11	1		2	9	2

Discussion:

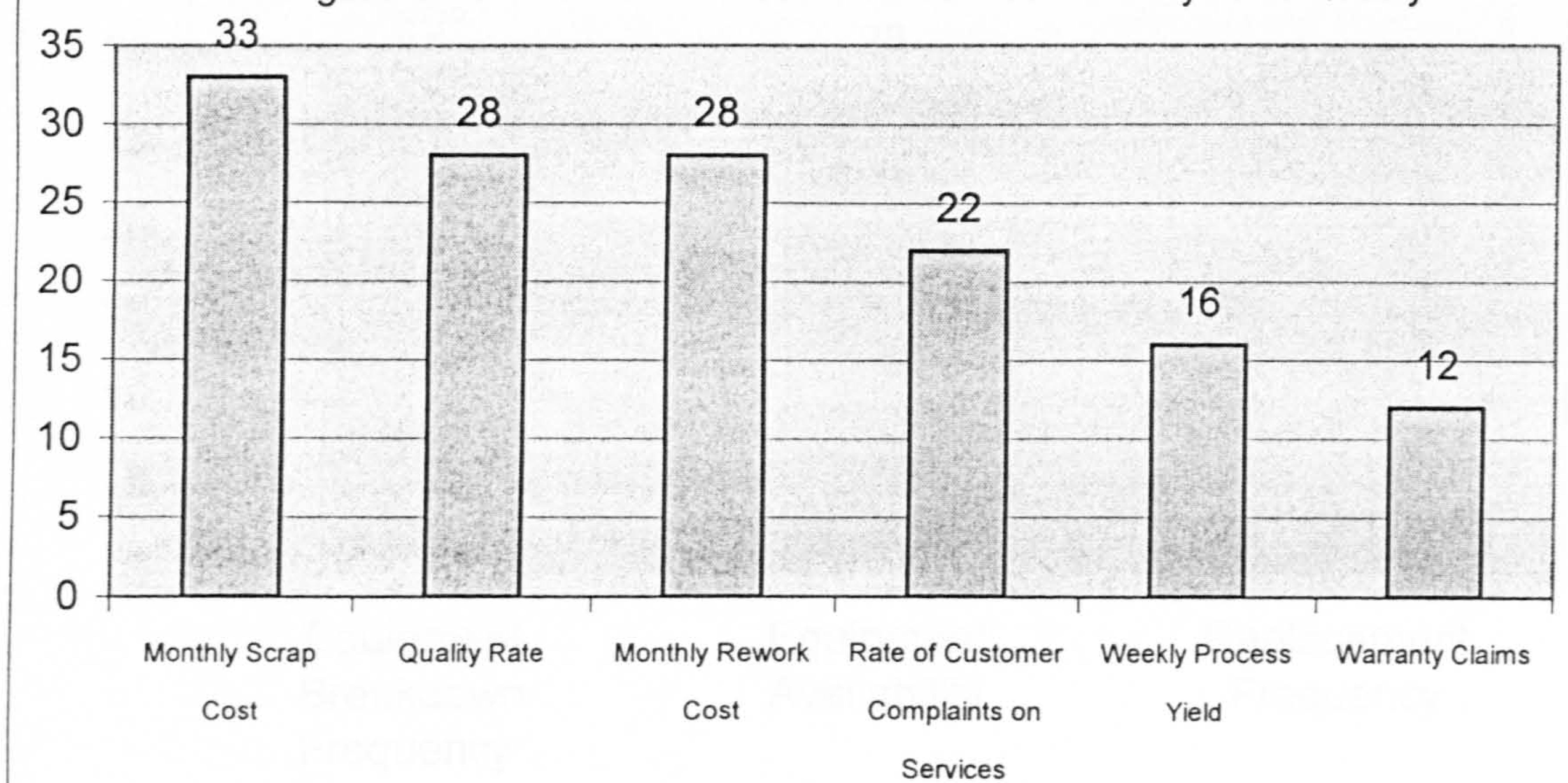
1. There are 78 Performance Indicators (P.I.) in this table. However, these P.I, are typical but not exhautive parameters for the performance monitoring.
2. After discussing with the interviewed companies, the best choices for the P.I. number is ocntroled within 12-14 items.
3. Several companies still using financial factors in maintenance/replacement decision making of the facilities. To the top management, the operational historic data are less important than the financial data which can be identified from the comparison of weight of importance of financial and operational performance indicators such as the maintainability, flexibility. However, the capacity and availability of the machines are pretty important.
4. From literature survey, many researchers advocate that the operational parameters should be paid attention than what they should have now.
5. From the interview, there is a gap between academic research and practical application in reality.

Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Quality)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Quality	Monthly Scrap Cost	33	12			3	9	1
	Quality Rate	28	10	2		2	8	2
	Monthly Rework Cost	28	11	1	1	3	7	3
	Rate of Customer Complaints on Services	22	7	5		2	6	4
	Weekly Process Yield	16	6	6		2	4	5
	Warranty Claims	12	4	7			4	6

Figure L.4 Performance Measures Utilisation Analysis in Quality

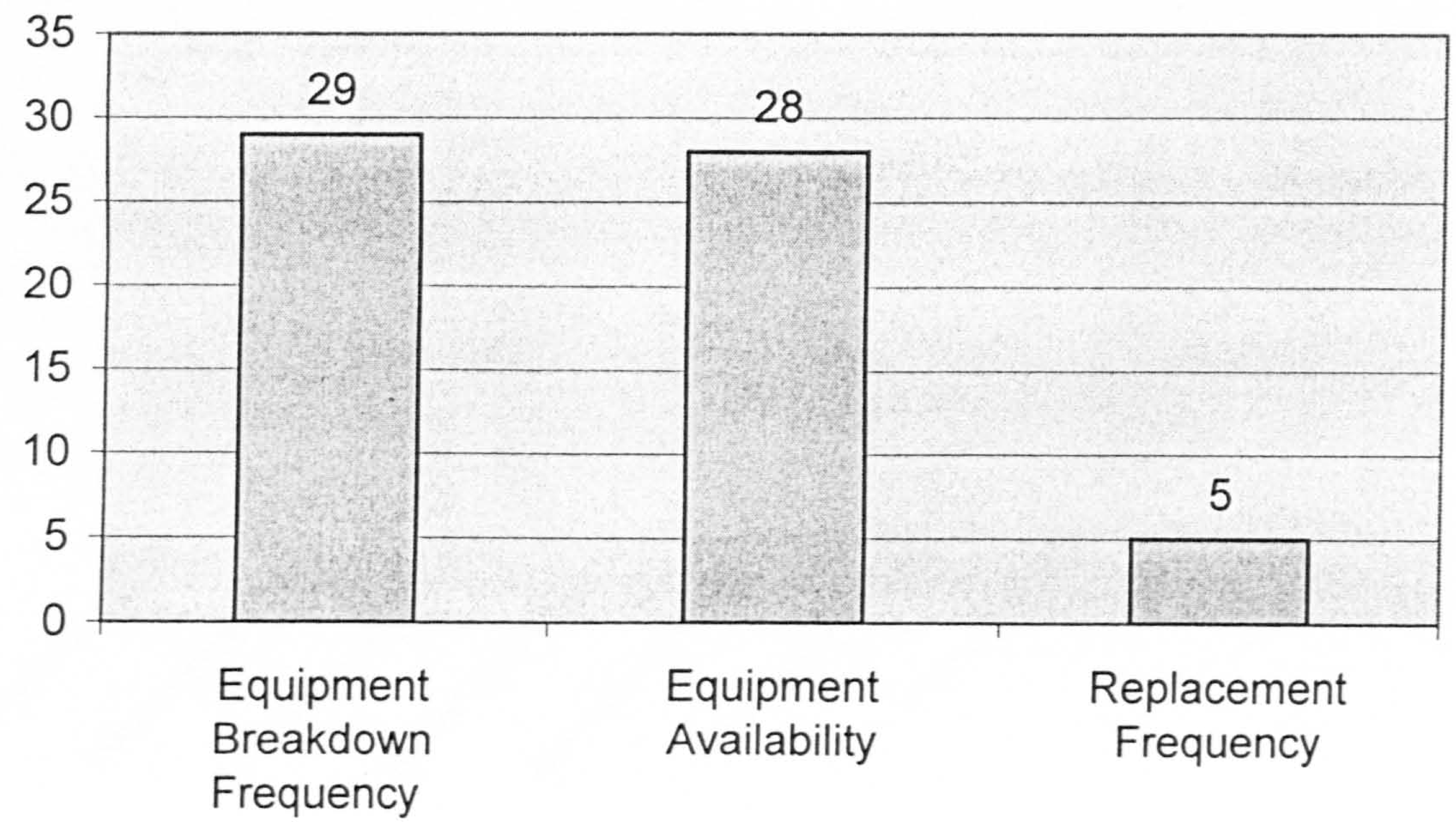


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Availability)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Total Weight	Priority of the Importance of Each P.I.
					Low	Medium	High		
Availability	Equipment Breakdown Frequency	29	10	2		1	9	29	1
	Equipment Availability	28	10	2		2	8	28	2
	Replacement Frequency	5	2	8		1	1	5	3

Figure L.5 Performance Measures Utilisation Analysis in Availability

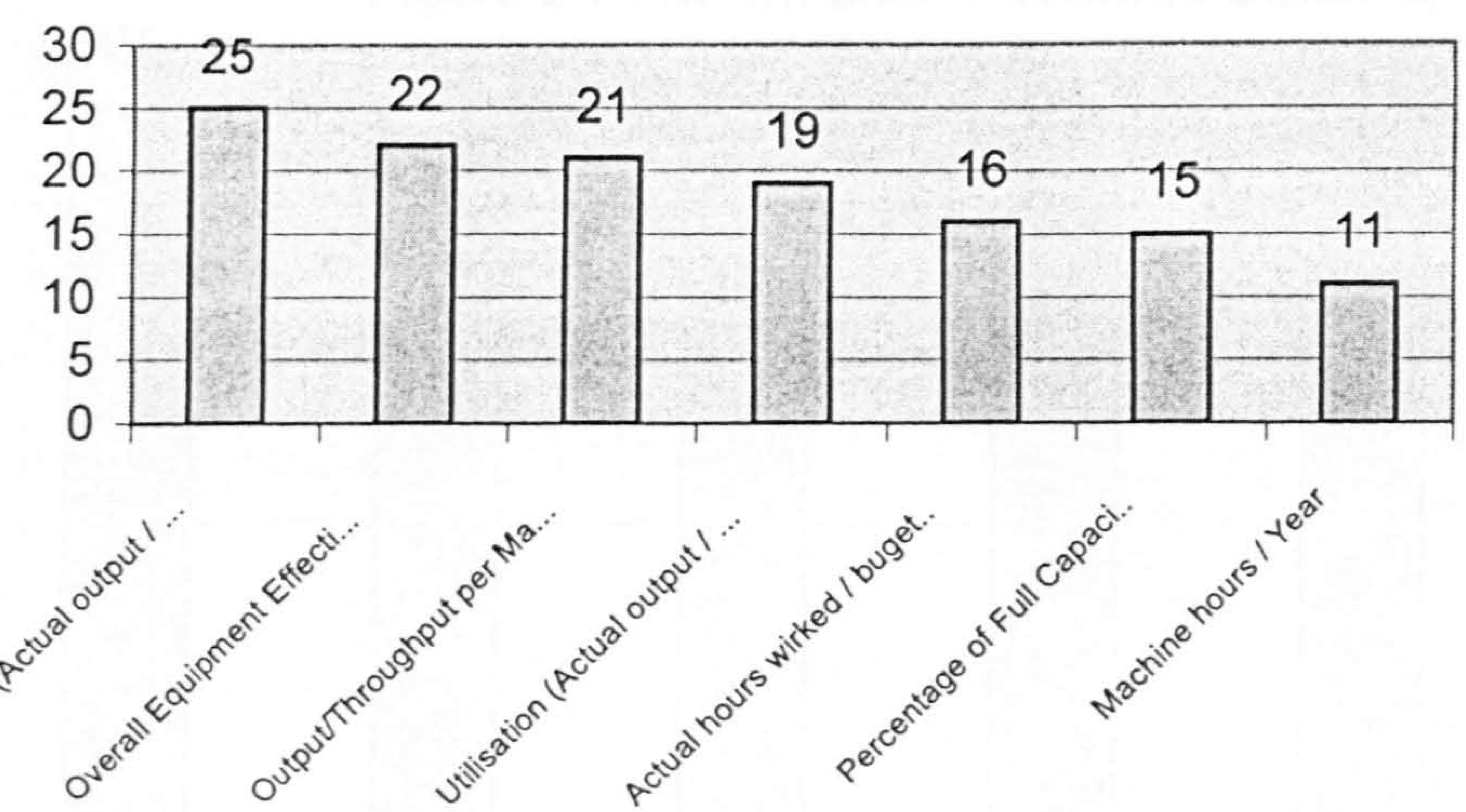


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Capacity)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Capacity	Effeciency (Actual output / effective capacity)	25	9	3		2	7	1
	Overall Equipment Effectiveness (OEE)	22	8	3		2	6	2
	Output/Throughput per Machine Hour	21	7	5		3	5	3
	Utilisation (Actual output / designed capacity)	19	7	5		2	5	4
	Actual hours wirked / bugeted standard hours	16	6	6		2	4	5
	Percentage of Full Capacity Normally Available	15	7	5	1	4	2	6
	Machine hours / Year	11	5	7	1	2	2	7

Figure L.6 Performance Measures Utilisation Analysis in Capacity

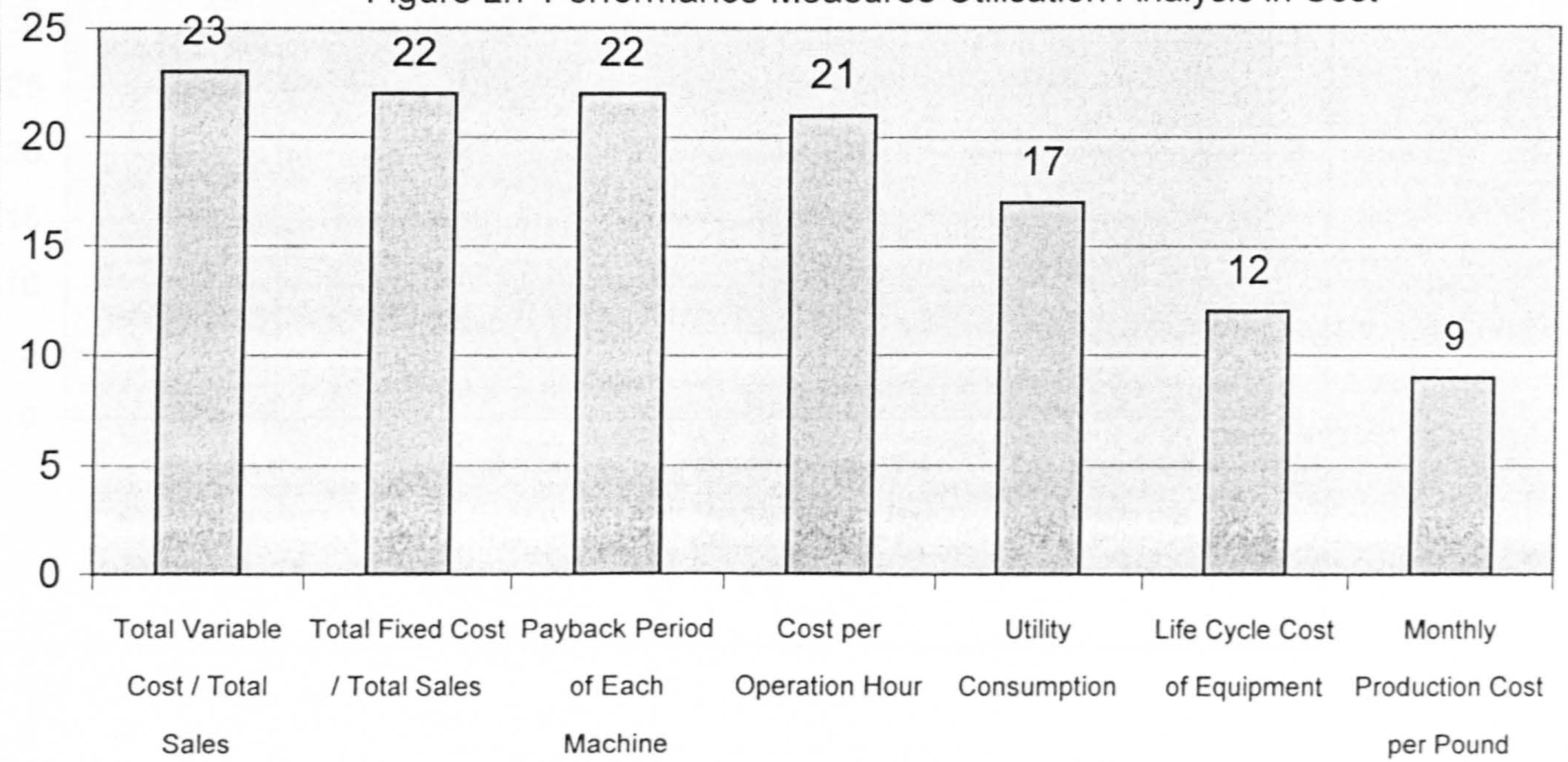


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Cost)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Cost	Total Variable Cost / Total Sales	23	10	2		4	5	1
	Total Fixed Cost / Total Sales	22	10	2		5	4	2
	Payback Period of Each Machine	22	9	3		5	4	3
	Cost per Operation Hour	21	8	4		3	5	4
	Utility Consumption	17	7	5	1	2	4	5
	Life Cycle Cost of Equipment	12	5	7		3	2	6
	Monthly Production Cost per Pound	9	4	8	1	1	2	7

Figure L.7 Performance Measures Utilisation Analysis in Cost

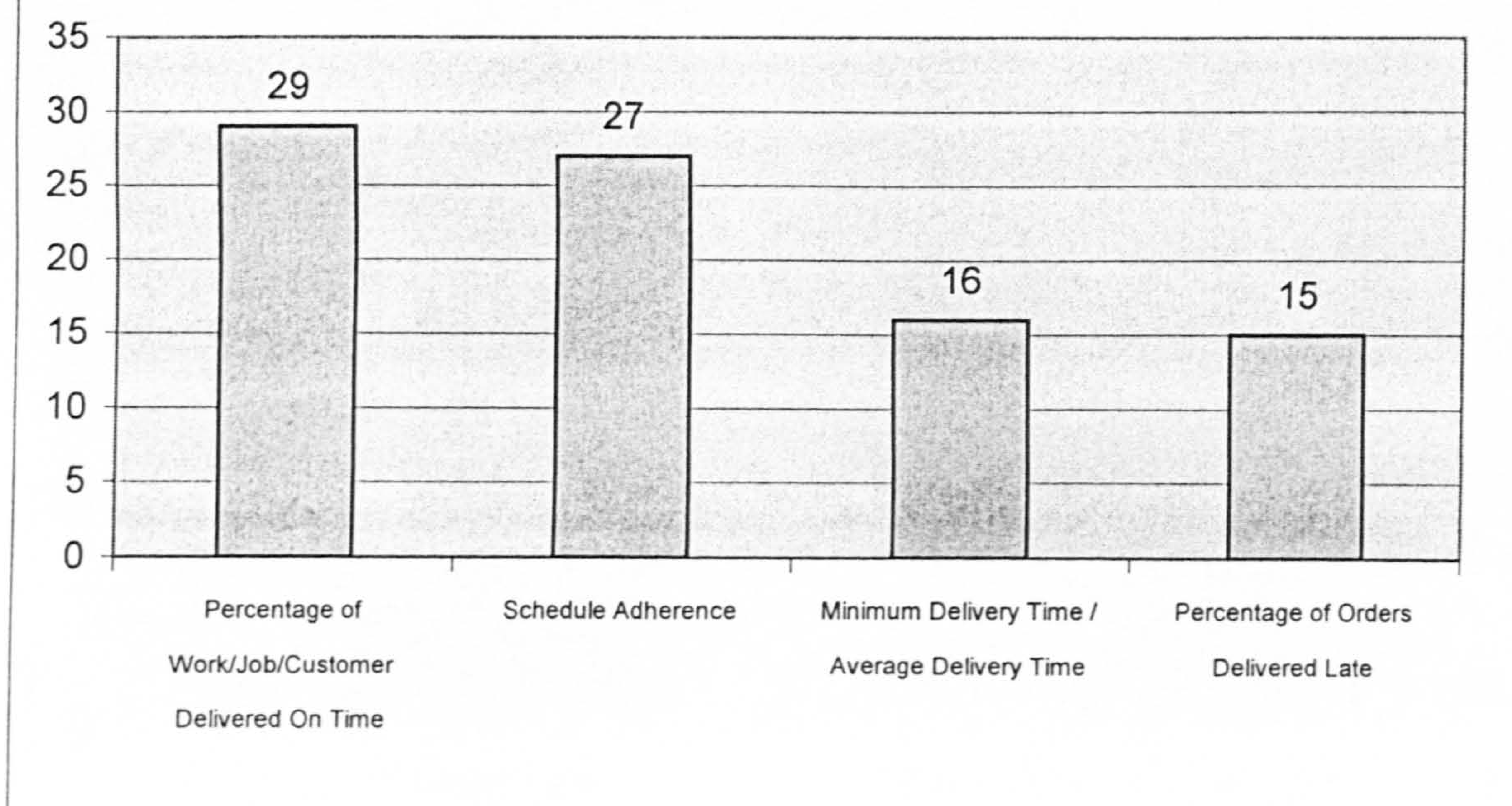


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Delivery)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Delivery	Percentage of Work/Job/Customer Delivered On Time	29	10	2		1	9	1
	Schedule Adherence	27	10	2		3	7	2
	Minimum Delivery Time / Average Delivery Time	16	7	5	1	3	3	3
	Percentage of Orders Delivered Late	15	6	6		3	3	4

Figure L.8 Performance Measures Utilisation Analysis in Delivery

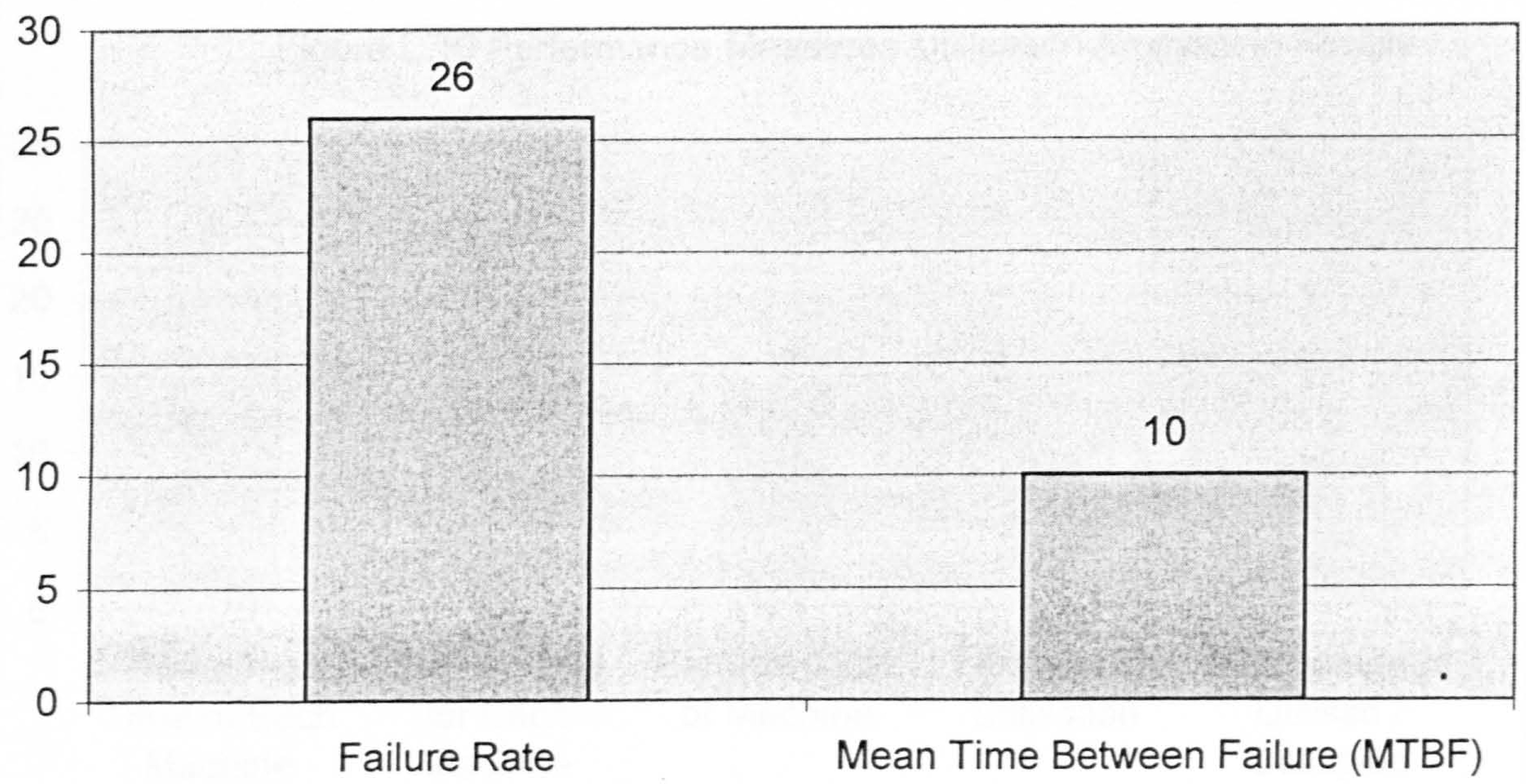


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Reliability)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Reliability	Failure Rate	26	9	3		1	8	1
	Mean Time Between Failure (MTBF)	10	4	8		2	2	2

Figure L.9 Performance Measures Utilisation Analysis in Reliability

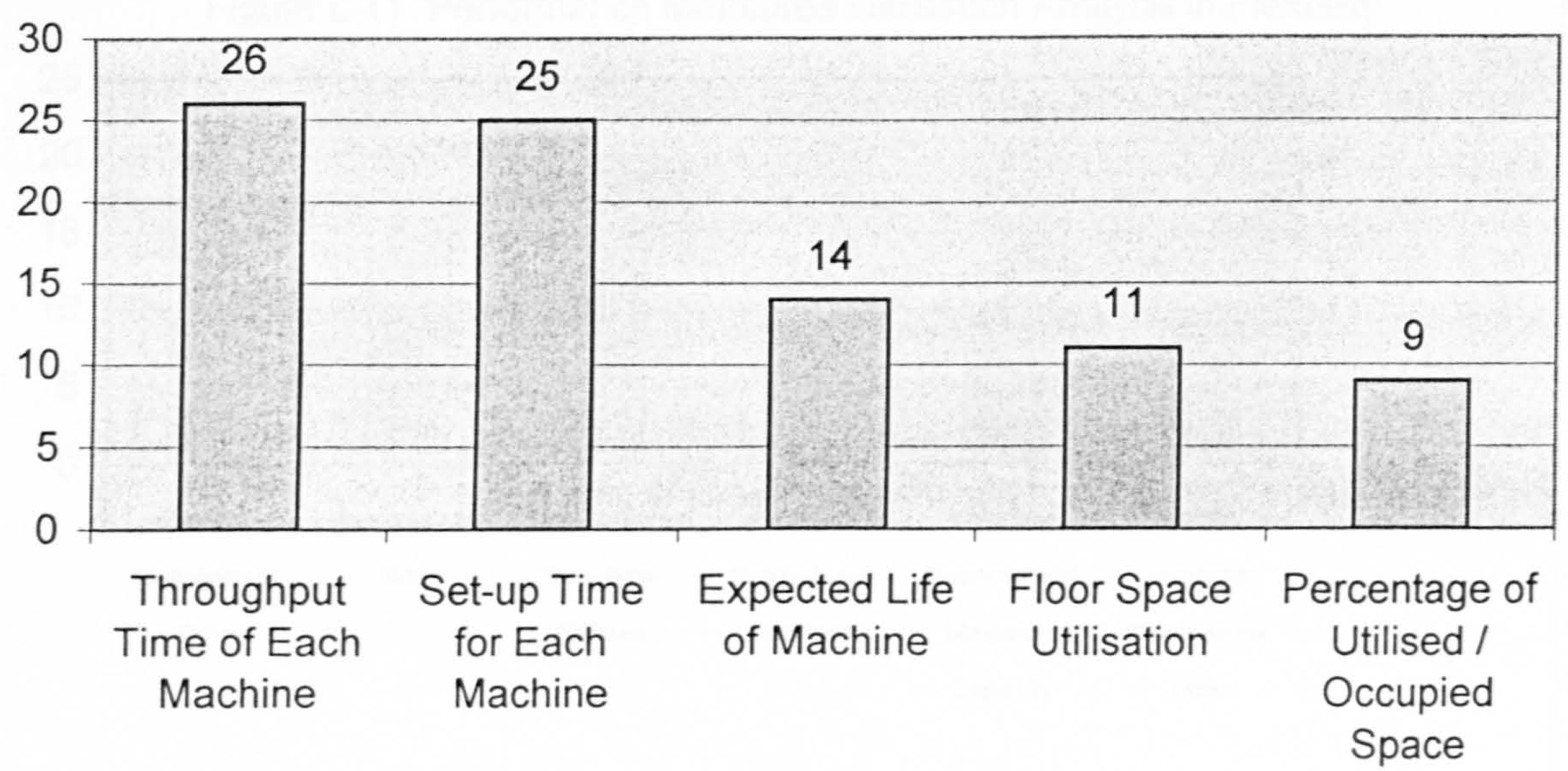


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Facility)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Facilities	Throughput Time of Each Machine	26	10	2	1	2	7	1
	Set-up Time for Each Machine	25	10	2	1	3	6	2
	Expected Life of Machine	14	6	6		4	2	3
	Floor Space Utilisation	11	6	6	1	5		4
	Percentage of Utilised / Occupied Space	9	5	7	2	2	1	5

Figure L.10 Performance Measures Utilisation Analysis in Facility

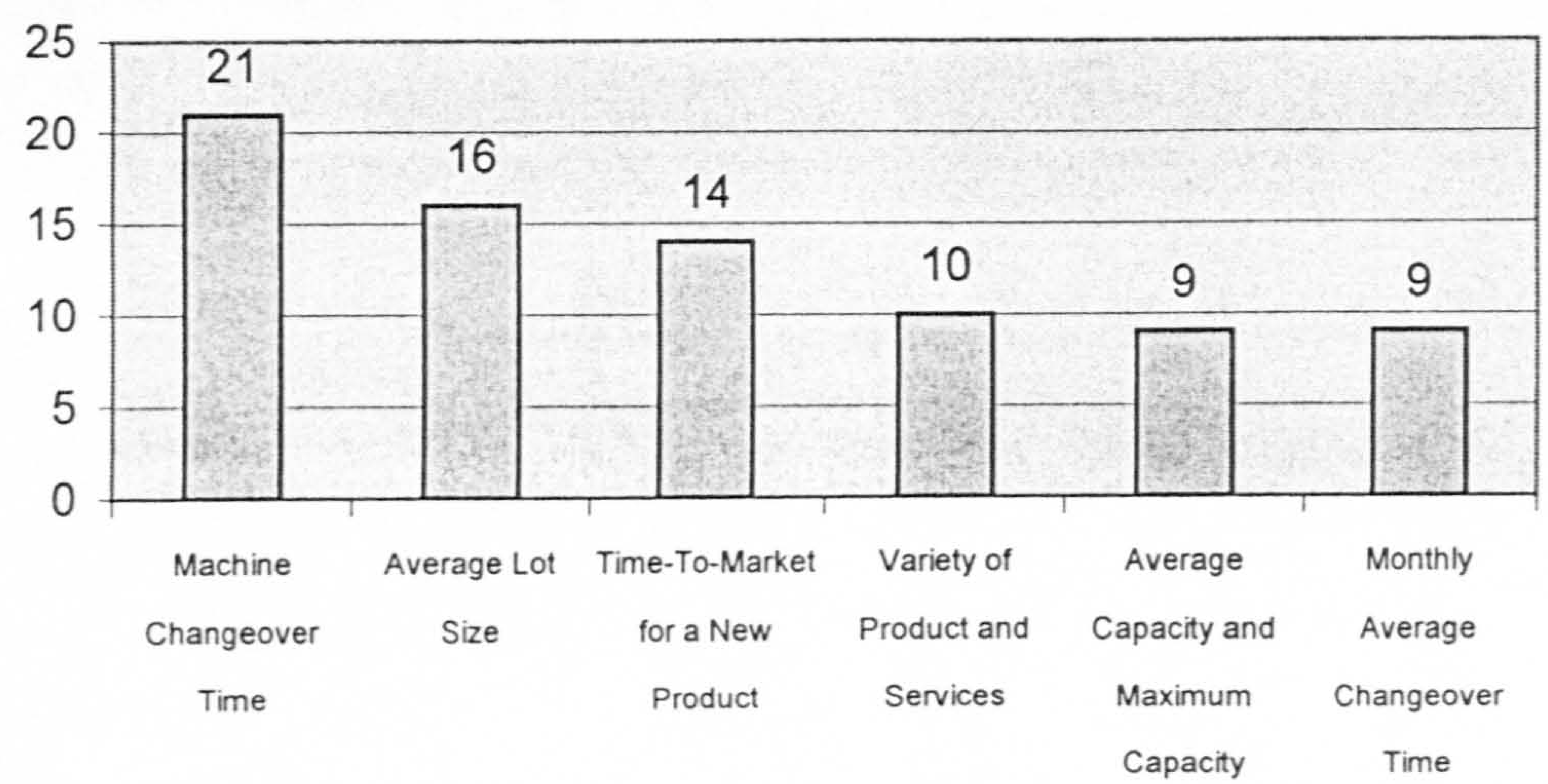


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Flexibility)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Flexibility	Machine Changeover Time	21	9	3		3	5	1
	Average Lot Size	16	8	4	2	4	2	2
	Time-To-Market for a New Product	14	6	6	1	2	3	3
	Variety of Product and Services	10	4	8		2	2	4
	Average Capacity and Maximum Capacity	9	5	7			3	5
	Monthly Average Changeover Time	9	4	8		3	1	6

Figure L.11 Performance Measures Utilisation Analysis in Flexbility



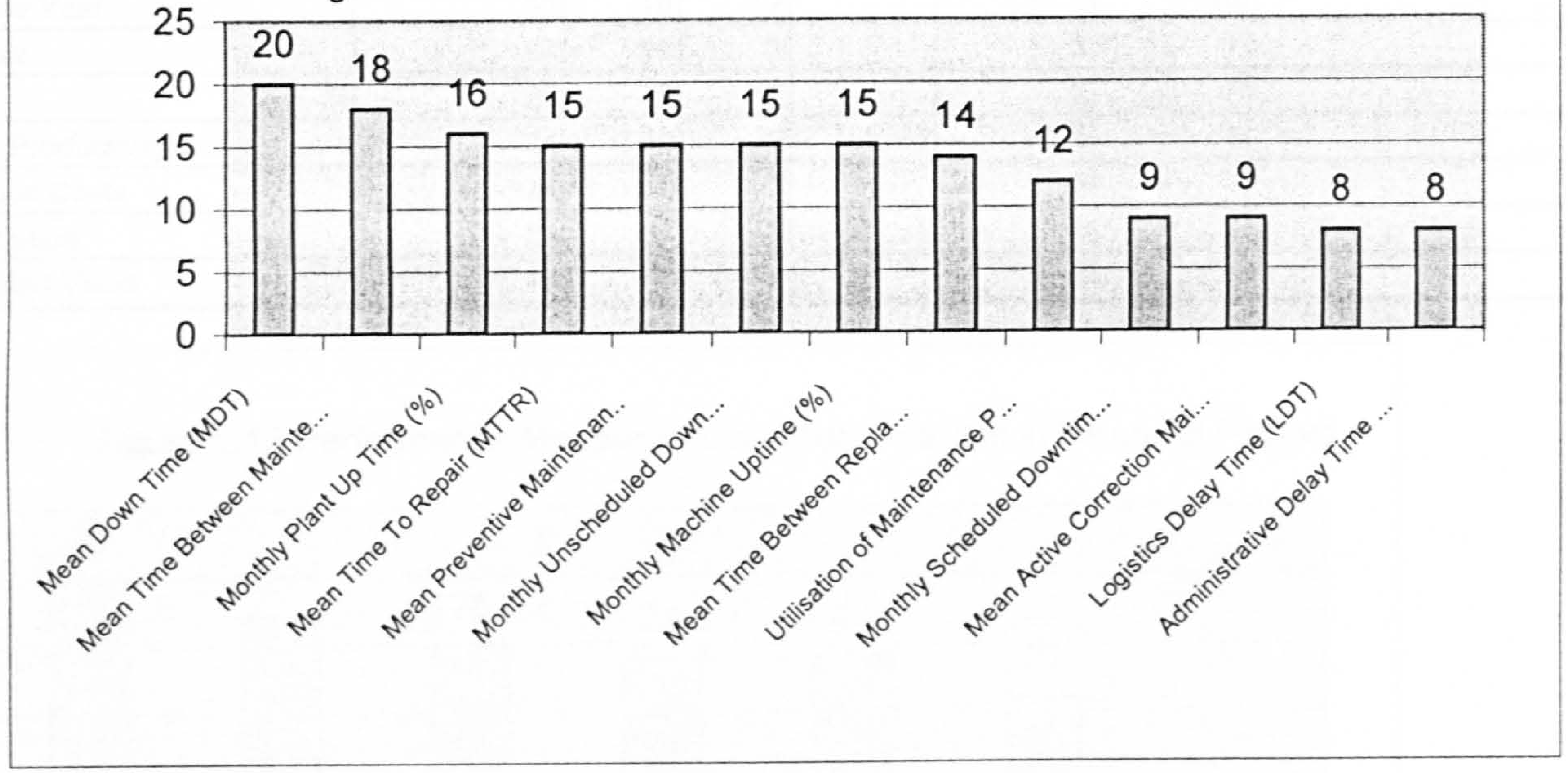
Question 4:Facilities performance measures utilisation (Maintainability)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Maintainability	Mean Down Time (MDT)	20	8	5	1	2	5	1
	Mean Time Between Maintenance (MTBM)	18	5	7			6	2
	Monthly Plant Up Time (%)	16	6	6		2	4	3
	Mean Time To Repair (MTTR)	15	5	7		3	3	4
	Mean Preventive Maintenance Time	15	6	6		3	3	5
	Monthly Unscheduled Downtime Percentage	15	6	6		3	3	6
	Monthly Machine Uptime (%)	15	6	6	1	1	4	7
	Mean Time Between Replacement (MTBR)	14	4	8		1	4	8
	Utilisation of Maintenance Personnel	12	5	7		3	2	9
	Monthly Scheduled Downtime Percentage	9	5	6		3	1	10
	Mean Active Correction Maintenance Time	9	3	9		3	1	11
	Logistics Delay Time (LDT)	8	2	10		4		12
	Administrative Delay Time (ADT)	8	2	10		4		13

Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Maintainability)

Figure L.12 Performance Measures Utilisation Analysis in Maintainability

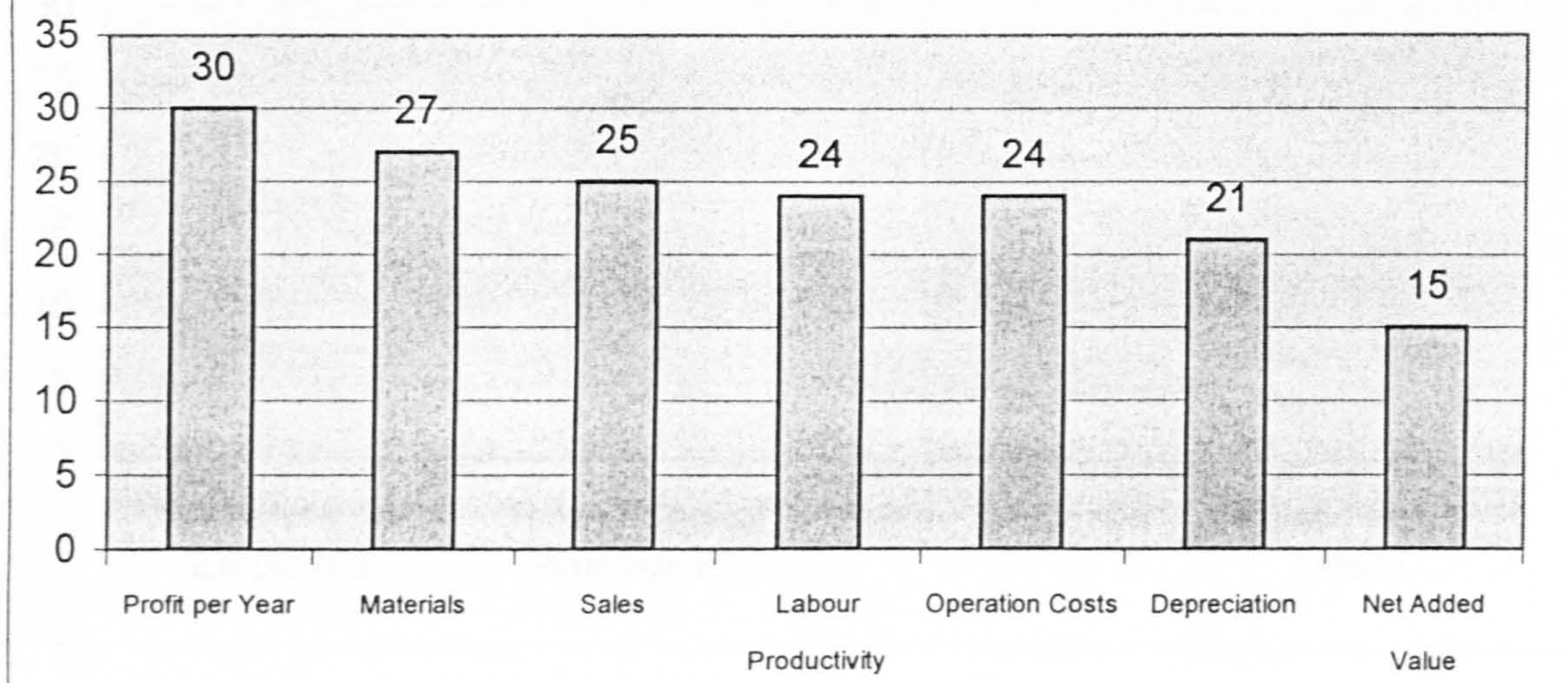


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Financial)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Financial	Profit per Year	30	10	2			10	1
	Materials	27	10	2		3	7	2
	Sales	25	9	3		2	7	3
	Labour Productivity	24	10	2	1	1	7	4
	Operation Costs	24	9	3		3	6	5
	Depreciation	21	9	3	1	4	4	6
	Net Added Value	15	6	6		3	3	7

Figure L.13 Performance Measures Utilisation Analysis in Financial Factors

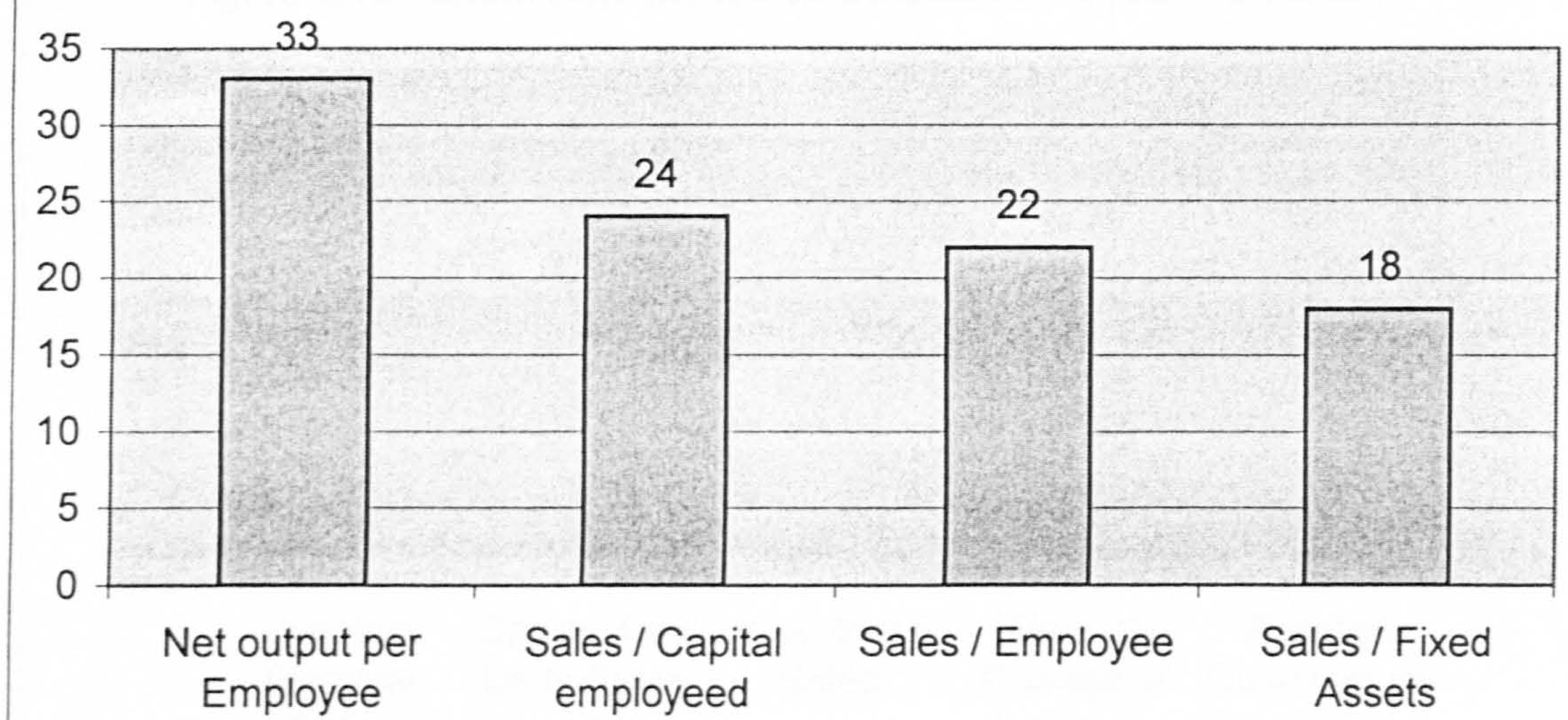


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Productivity)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Productivity	Net output per Employee	33	11	1			11	1
	Sales / Capital employeed	24	9	3		3	6	2
	Sales / Employee	22	8	4		2	6	3
	Sales / Fixed Assets	18	6	6			6	4

Figure L.14 Performance Measures Utilisation Analysis in Productivity

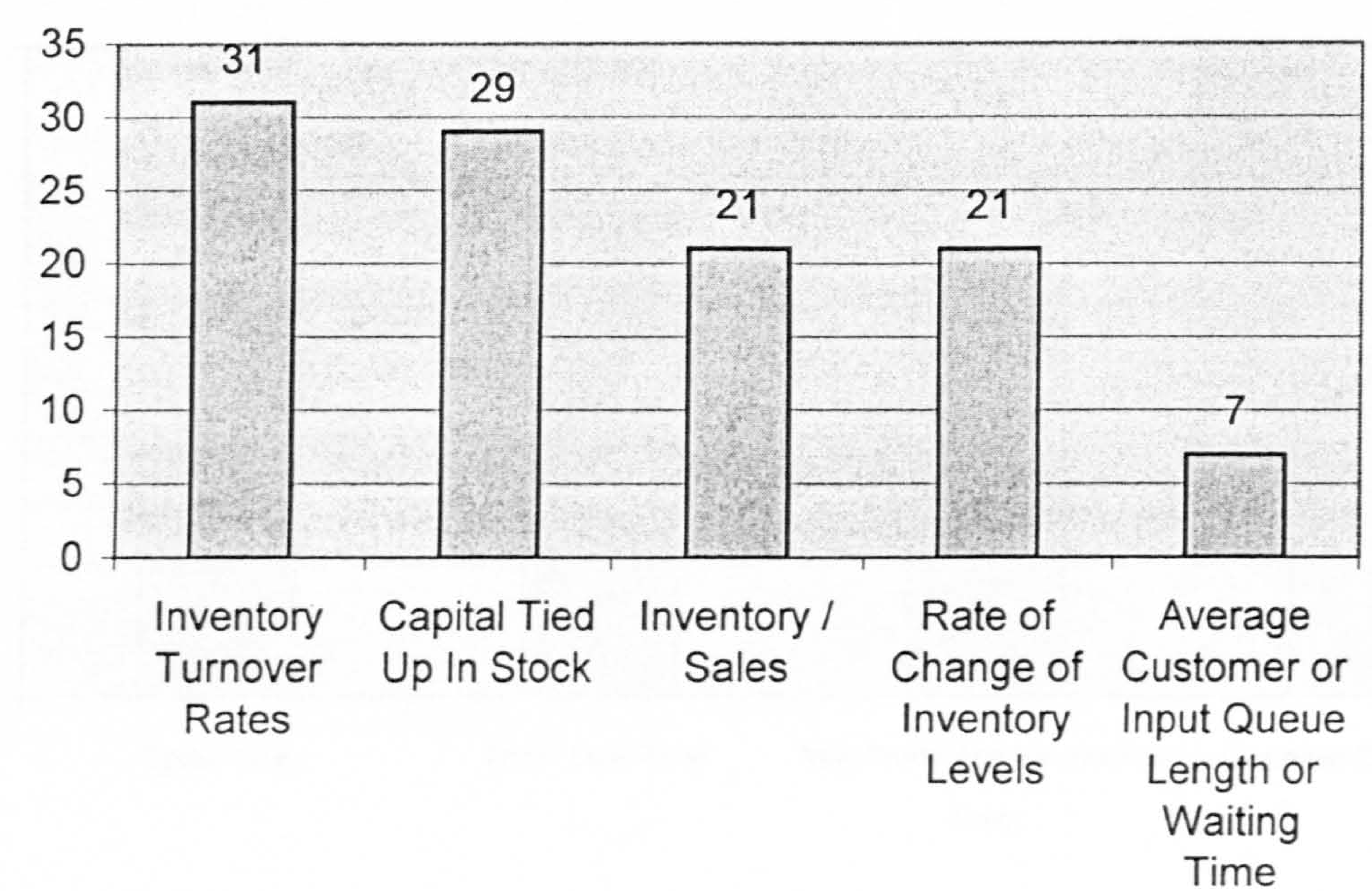


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Inventory)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Inventory	Inventory Turnover Rates	31	12		1	3	8	1
	Capital Tied Up In Stock	29	11	1		4	7	2
	Inventory / Sales	21	8	3		3	5	3
	Rate of Change of Inventory Levels	21	9	3	1	4	4	4
	Average Customer or Input Queue Length or Waiting Time	7	3	9		2	1	5

Figure L.15 Performance Measures Utilisation Analysis in Inventory

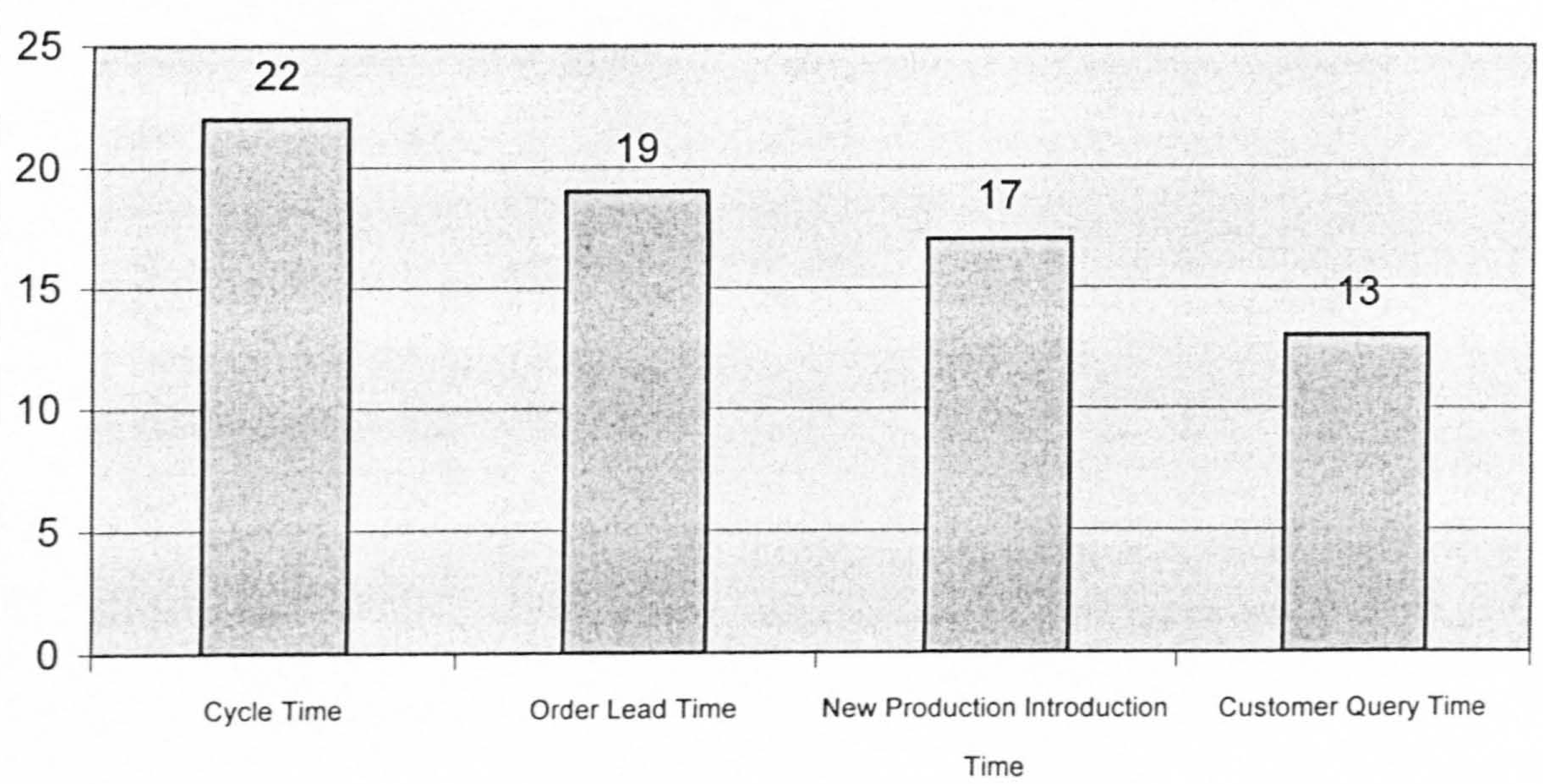


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Speed)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Speed	Cycle Time	22	8	4	1		7	1
	Order Lead Time	19	7	5		2	5	2
	New Production Introduction Time	17	7	5	1	2	4	3
	Customer Query Time	13	5	7		2	3	4

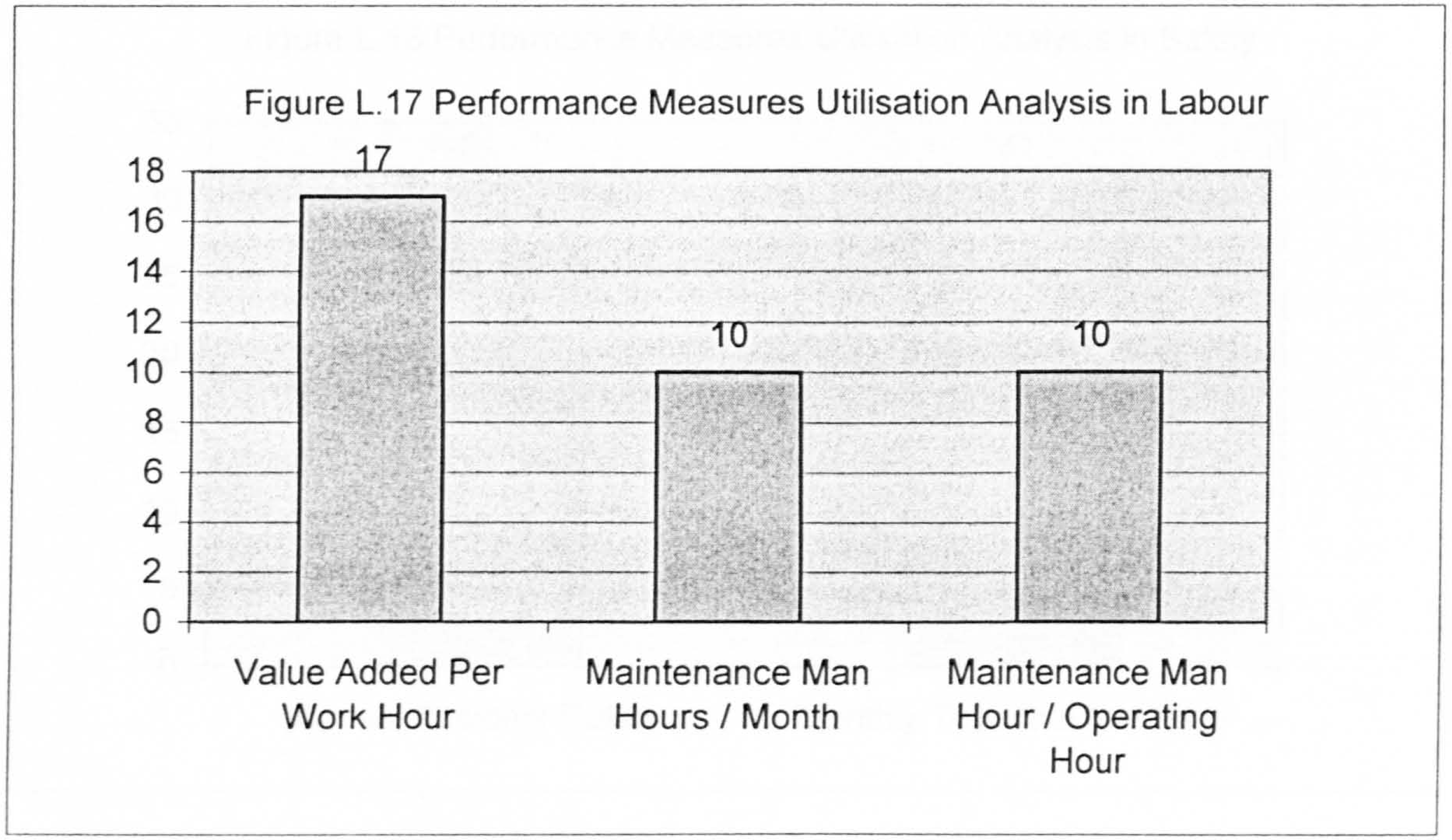
Figure L.16 Performance Measures Utilisation Analysis in Speed



Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Labour)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Labour	Value Added Per Work Hour	17	6	6		1	5	1
	Maintenance Man Hours / Month	10	4	8		2	2	2
	Maintenance Man Hour / Operating Hour	10	4	8		2	2	3

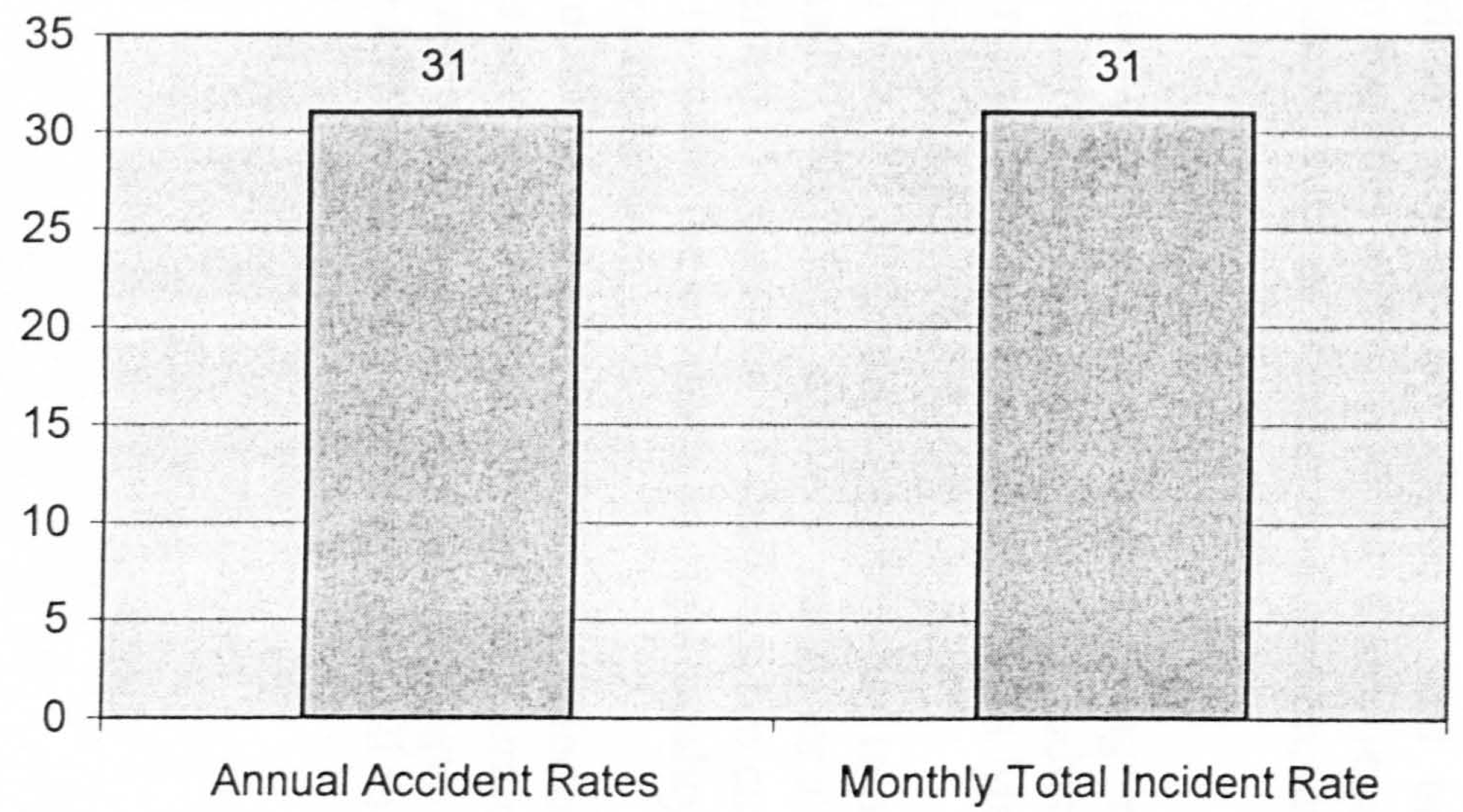


Appendix L Questionnaire Survey Results

Question 4:Facilities performance measures utilisation (Safety)

Performance Measures (P.M.)	Performance Indicators (P.I.)	Total Weight	Used	Not Used	Weight of Importance			Priority of the Importance of Each P.I.
					Low	Medium	High	
Safety	Annual Accident Rates	31	11	1		2	9	1
	Monthly Total Incident Rate	31	11	1		2	9	2

Figure L.18 Performance Measures Utilisation Analysis in Safety



Appendix M

DEVELOPMENT OF A STRATEGICALLY DRIVEN PRODUCTION FACILITIES MANAGEMENT (PFM) FRAMEWORK

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Key Words: Production Facilities Management (PFM), Manufacturing Strategy, Performance Measurement, Multiple Criteria Decision-Making (MCDM)

ABSTRACT

Production Facilities Management (PFM) is the activity of managing production facilities to fully realise the corporate strategic objectives of a manufacturing organisation. This paper describes the development of a strategically driven, step-by-step approach that helps a company to measure the performance of existing production facilities and to forecast future requirements. The process will help users to make appropriate PFM decisions, such as whether to maintain, enhance or replace equipment.

1. INTRODUCTION

Keen competition in industry and customers' never ending change requirements places manufacturers under constant pressure to become more efficient. This forces the industry to evolve towards being more flexible and productive [1]. Many researchers have set World-Class Manufacturing (WCM) standards to help achieve this dynamic requirement [2,3,4,5,6,7,8,9,10].

From a strategic viewpoint, to be a WCM means a business has to achieve best performance in major competitive criteria such as cost, quality, flexibility, delivery, customer service. From a practical operations viewpoint, appropriate PFM is essential to guarantee all facilities are capable of satisfying these strategic objectives. PFM is required so as to make the products in right quality, minimum cost, deliver them to customer right on time for customer satisfaction.

The issue in implementation of PFM is that it involves much indecision due to a range of decision-makers with conflicting perceptions and requirements. From the literature surveyed, there is an apparent lack of a systematic, step-by-step approach to link corporate strategic requirements into the production facility management activities. The PFM framework is designed to fill this gap.

2. PFM FRAMEWORK OVERVIEW

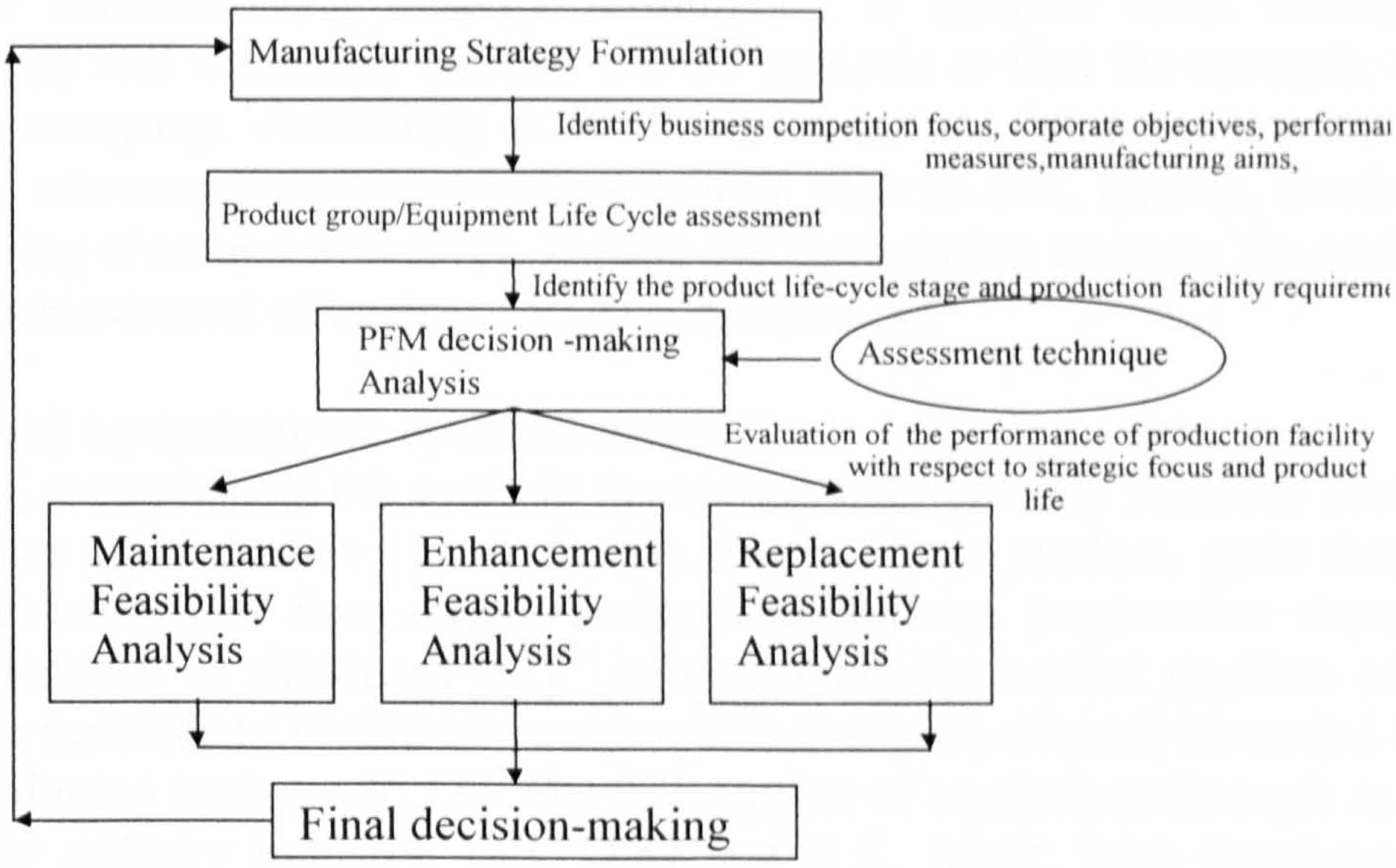

Figure 1. Overview of PFM process

The key factors in this evolutionary process are those affecting a manufacturing company's competitive position, such as: product and service quality, cost, manufacturing lead-time and flexibility. The basic concept of this strategically driven approach to PFM is based on a framework developed previously by the Computer Aided Manufacturing Systems Design research team at Cranfield University [11].

The framework has been further developed to reflect PFM requirements. As shown in Figure 1, there are four key elements in this framework, they are manufacturing strategy formulation, product/equipment life cycle assessment process, production facility performance monitoring and utilisation analysis. In order to solve intermixed tangible and intangible calculations, the research is also searching for a suitable weighting methodology, such as Analytic Hierarchy Process (AHP) [1]. The detailed design of the whole framework has been developed with several steps which are shown as Figure 2.

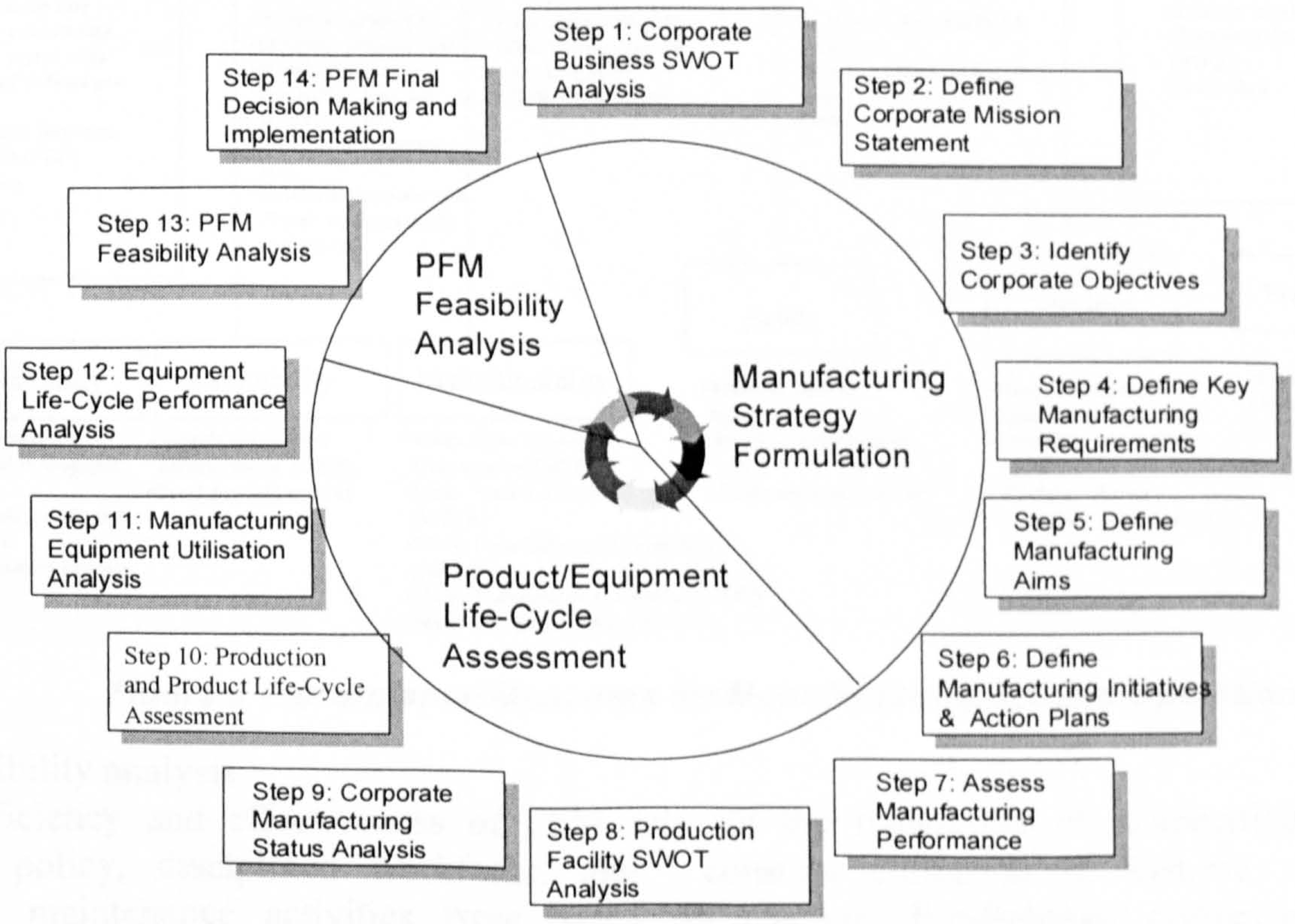

Figure 2. Production Facilities Management (PFM) Framework Overview

2.1 Manufacturing strategy formulation

The stage of manufacturing strategy formulation is initiated from benchmarking the business performance internally and externally through SWOT analysis to find the strength, weakness, opportunity and threats of the company. According to its business status, the company can develop its strategic objectives based on aforementioned competitive criteria such as cost, quality, flexibility, etc., sequentially develop manufacturing aims and initiatives. During the formulation process, the performance measures for benchmarking the achievement of business are also decided [1].

2.2 Product group and equipment life cycle assessment

Every product group has its life cycle in the market that typically includes market entry, fast growth, maturity, decline and rapid decline [1]. A facility, much like a product, goes through a life cycle. The facilities life cycle consists of four stages: design and start-up, progressive expansion, maturation and reinvestment, and renewal or shutdown [12]. Understanding the market position of each product and the status of production facilities to ensure all equipment is available when it is needed by operations planners is a vital factor of winning business [6,13]. The full support of equipment through its life cycle is extremely important in strictly military industry. U.S. DoD and U.K. MoD. have developed Integrated Logistics Support (ILS) and Computer Aided Logistic Support (CALS) technologies which utilise Electric Data Interchange (EDI) technology to assist operation data collection, recording, analysis and support decision-making in facility operations management [14]. Typical, but not exhaustive, parameters related to the strategic objectives to monitor the performance of production facilities are introduced as Figure 3. Different companies may develop their own parameters to fit their strategic objectives.

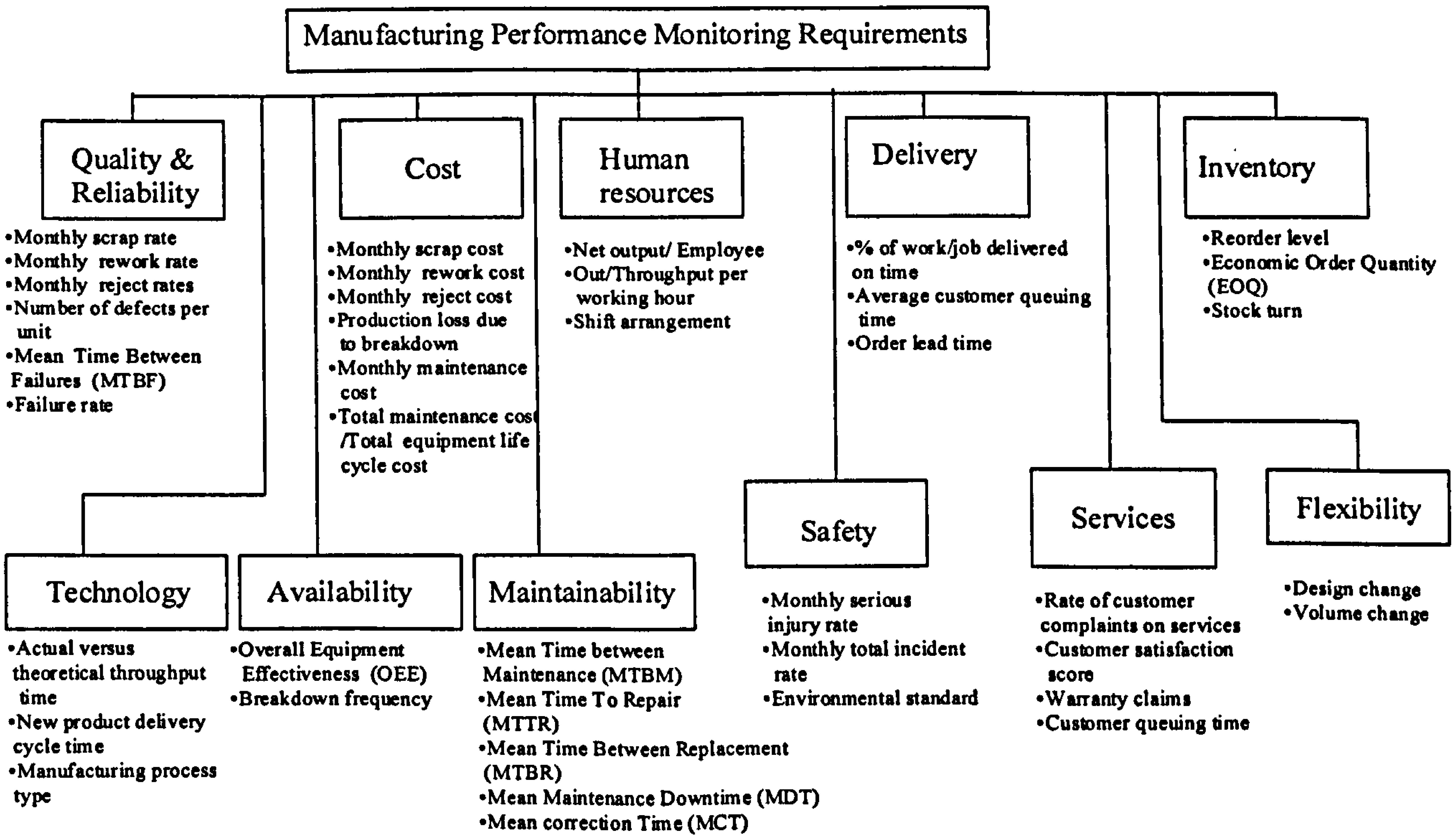

Figure 3 Performance Measures for Manufacturing System Operation

2.3 PFM feasibility analysis

The efficiency and effectiveness of PFM rely on the integration of a specified business and maintenance policy, disciplined workforce, and constant collection of historic operation data. Traditionally, maintenance activities were based on reactive, fire-fighting, corrective maintenance approaches, or on Planned Maintenance (PM) practices that take mainly the form of equipment overhaul or item repair, item replacement at fixed intervals [15,16]. In 1996, a downtime survey indicated that around one third of UK manufacturing companies were taking a 'laissez-faire' stance on downtime and not taking significant steps to address the associated problems. It also concluded that reduction of production downtime is a strategic business issue and has a major impact on the bottom line. Lack of understanding of the real cost of production downtime and failure to adequately address the problem lead to poor line efficiency [17].

Over the past twenty years, more and more researchers reported that due to the huge increase in the number and variety of physical assets (plant, equipment, and buildings), maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. Maintenance is responding to changing expectations [18,19]. These include a rapidly growing awareness that the maintenance objective is compatible with the corporate and production objectives such as safety, product quality, plant availability, cost, etc. Effective strategies deliver plant reliability and good maintenance emphasises the need to consider plant reliability within a wider context of corporate and production objectives [13]. The decision-making on maintaining, enhancing or replacing the existing facilities should be based on historic maintenance records and downtime analysis and effective PFM needs well disciplined maintenance.

2.4 Decision-making support

By defining the key strategic manufacturing requirements, assessing product life cycle and performance of the existing production facilities, it would allow the management to look at the optimised operation management in the production facilities investment of the future. The feasibility analysis of PFM is a typical Multiple Criteria Decision-Making (MCDM) process. In this MCDM process, several linking tables are developed to link detailed steps and assist the feasibility analysis in PFM. An example linking tabls, which is used to identify the manufacturing requirements versus different product group life cycle stages, is demonstrated in Figure 4.

Corporate strategy requirement		Product Group/Project Life Cycle				
Item	Competitive criteria	Concept	Design and Development	Production (Maturity)	Decline	Rapid decline
1	Cost	••••	••••	•••••	•••	••
2	Quality	••	•••	•••••	•••	••
3	Delivery	•	•	••••	••	•
4	Flexibility	•••••	••••	•••	••	•
5	Price	•••	•••	••••	••	•
6	Speed	•••••	•••••	•••	••	•
7	Service	•	••	••••	••••	•••

* Symbol "•••••" means most significant, " • " means less important

Figure 4 Corporate Manufacturing Status Analysis Table (for PFM step 9)

3. CONCLUSIONS

Demands on manufacturing industry to provide right quality, high flexibility, short lead time, and to reduce costs have put pressures on manufacturing companies to improve the maintainability, reliability, availability, and supportability of their production facility. The development of a strategically driven PFM framework provides guidance in decision-making of maintaining, enhancing or replacing existing facilities in order to assure the production facilities can accomplish the organisational strategic requirement.

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